PSC
Theater

ELEMENTARY PHYSIOGRAPHY

ELEMENTARY PHYSIOGRAPHY

AN INTRODUCTION TO THE STUDY OF NATURE

BY

JOHN THORNTON, M.A.

HEAD MASTER OF THE CENTRAL HIGHER GRADE SCHOOL, BOLTON
AUTHOR OF "ADVANCED PHYSIOGRAPHY," ETC.

WITH 13 MAPS AND 296 ILLUSTRATIONS

TENTH EDITION
Revised and Partly Rewritten

LONGMANS, GREEN, AND CO.
39 PATERNOSTER ROW, LONDON
NEW YORK AND BOMBAY
1899

PREFACE

THIS volume is intended to serve as an elementary introduction to Science. It supplies such a knowledge of the facts and laws of Nature as is implied in the expressive term *Physische Erdkunde*—an acquaintance with the physical phenomena of the earth.

The treatment is somewhat fuller than that adopted in some elementary books, as I believe that a meagre account, with a single figure, of such a subject as Volcanoes, for example, only leads to inaccurate and confused ideas. Numerous illustrations and maps have been introduced, as an aid both to the understanding and memory. Some of these have been drawn expressly for the book, while others have been derived from Rutley's "Study of Rocks;" Helmholtz's "Scientific Lectures;" Thorpe and Muir's "Qualitative Analysis;" Peschel and Leipoldt's "Physische Erdkunde;" Haughton's "Lectures on Physical Geography;" Ganot's "Physics;" Jago's "Chemistry;" Reynolds's "Chemistry;" "*Challenger* Reports," vol. xvi.; Chisholm's "Geography;" Treglohan's "Magnetism;" Ball's "Astronomy;" Brinkley's "Astronomy;" Proctor's "Seasons." The various instruments and apparatus regarded as indispensable by the Science Department, as well as others that are necessary for effective teaching, have been carefully described. The teacher is advised to make his lessons as much experimental as possible. Specimens of the various rocks and minerals may be obtained from several London dealers, and the pupils will readily gather a number of the commoner ones for themselves.

For some information on the Ordnance Survey and its maps

I am indebted to Lieutenant-Colonel T. P. White, R.E., Executive Officer of the Survey.

Among the books consulted in the preparation of this work may be mentioned Ganot's "Physics;" Professor Ball's "Elements of Astronomy;" Dr. A. Geikie's "Text-Book of Geology;" the treatises on "Physical Geology" by Professor Prestwich and Professor Green; "Histoire Naturelle des Pierres et des Terrains," by Meunier; "Volcanoes," by Professor Judd; "Elementary Meteorology," by R. H. Scott; and the two volumes of the "*Challenger* Reports," entitled "Narrative of the Cruise, with a General Account of the Scientific Results of the Expedition." Other obligations are acknowledged in the pages of the book.

In conclusion, I beg to express my thanks to two or three friends for some assistance in reading over the proof-sheets.

JOHN THORNTON.

ALBERT PLACE, BOLTON,
February, 1888.

PREFACE TO TENTH EDITION

CONSIDERABLE changes have been made in this edition in order to adapt the book to the present Syllabus of the Science and Art Directory. The earlier part, covering Section I. of the Syllabus, has been almost entirely rewritten and supplied with many new illustrations. A fuller and more detailed treatment of this portion will be found in my "Elementary Practical Physiography, Section I." In the portion of the book that deals with Section II. of the Syllabus, many small improvements and alterations have been effected, while those parts of the former editions that are not now needed have been omitted. It is hoped that the book in its new and improved form will prove itself as helpful and trustworthy as it did before.

For many useful suggestions and much valuable help I have been indebted to my son, Mr. A. L. Thornton, B.Sc.

The new coloured map has been derived from Longmans' New Atlas.

BOLTON,
October 2, 1899.

CONTENTS

MAPS

ELEMENTARY PHYSIOGRAPHY

INTRODUCTION.

PHYSIOGRAPHY (Gr. *phusis*, nature; and *grapho*, I write), according to its derivation, is a Description of Nature. The word *Nature* is used in several meanings, but in this connection it may be taken to stand for the general system of created things, including their constitution and properties. All the objects and facts belonging to this material world on which we live, as well as the objects and facts belonging to the other worlds that occupy space, are included in the word "Nature." Hence we may say that the word "Nature" stands for the world and all upon it, or even for the universe. The sun, moon, and stars; the sky, the clouds, and the wind; the sea, the shore, and the rocks; the mountains, plains and valleys, plants and animals, are all comprised in the term "Nature" or "Natural Objects." Even what are called Artificial Objects are only natural things shaped and altered by the art of man.

By the use of our senses and by the action of our mind we learn what the different objects of the world are, and what are the different properties or qualities that these objects possess. In this way we arrive at ideas of cause and effect; for we say that such an object is the cause of the sensation or effect that we observe. The fall of a stone when unsupported, and the formation of a cloud in the air, are effects, and it is our aim to ut the cause or reason of these *phenomena*. (The Greek *phenomenon*, plural *phenomena*, is used to signify appear-e, object, or occurrence.) We have all a tendency to

B

seek after causes, and when we have discovered the cause or reason of any frequently occurring phenomena we are said to have *explained* them. This explanation or statement of the general cause of certain effects is often called a Law of Nature. Thus it is a law of nature that an unsupported body falls to the ground; it is a law of nature that at the ordinary summer temperature of the air water is a liquid, but that when the temperature falls below a certain point it becomes a solid. Accurate and systematic knowledge of the various laws of nature forms what is called Science; and this is acquired by careful observation, experiment, and reasoning.

Now, the study of nature is a very wide and extensive study, and although all knowledge is connected, yet for the sake of convenience it is divided into various branches or departments. Among these branches or sciences we have *physics*, *astronomy*, *chemistry*, *geology*, and *biology*. The physical sciences are often spoken of under the term Natural Philosophy, and embrace *mechanics*, which treats of force and motion, and the sciences of *heat*, *light*, *electricity*, and *magnetism*. *Astronomy* is the science which treats of the heavenly bodies, and among other things gives an account of the earth as a member of the solar system; *chemistry* deals with the composition of substances and the combinations of different kinds of matter; *geology* furnishes information regarding the arrangement and history of the materials forming the crust of the earth; while *biology* or *natural history* gives an account of the phenomena of life both vegetable and animal, the account of vegetable life constituting the science of *botany*, and the account of animal life being called *zoology*.

It is plainly impossible to give in one small book anything like a complete account of these different sciences. But we can endeavour to learn some of the most important facts and laws from those that come under our daily notice. Such a rudimentary course of instruction in science, such a general description and explanation of common natural phenomena, is what is meant by ELEMENTARY PHYSIOGRAPHY.

CHAPTER I.

MATTER AND ITS PROPERTIES.

1. **Matter and Quantity of Matter.**—That which under suitable circumstances is able to excite several of our sense-organs at the same time is called matter. The name "matter" is given to anything that possesses weight, and to anything that can receive or communicate motion. As all matter takes up a certain amount of room, it may be defined as follows :—

Matter is that which occupies space exclusively.

The property of occupying a portion of space is called *extension ;* the property of occupying a certain portion of space to the exclusion of all other matter is called *impenetrability.* This property of impenetrability is shown by the inability of one body to enter into the space occupied by another.

Experiment 1.—Press an "empty" glass cylinder or a tumbler mouth downwards into a vessel of water, and it will be noticed that the water enters but little, owing to the invisible matter called air occupying the space. Tilt the cylinder to one side while the mouth is still under water, and notice that as the air escapes in bubbles the water then enters. Now fill the cylinder with the water in the vessel by letting the air escape. Lift it upright so as to keep its mouth just below the level of the water in the larger vessel, and it will be noticed that the water remains in the cylinder, being kept there by the pressure of the atmosphere on the exposed water-surface (par. 167). Take a second cylinder filled with air or any other gas, and transfer this gas to the first cylinder in the way shown in Fig. 1. As the light gas rises in bubbles through the water in the first cylinder, the water is displaced, the air and the water not being able to occupy the same space at the same time.

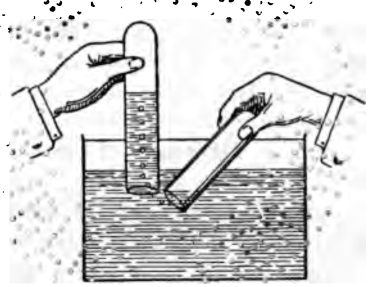


FIG. 1.—Air is matter, and occupies space.

A **substance** is a definite kind of matter, *e.g.* gold, wax, milk, coal-gas, etc. Each substance or material has properties which distinguish it from all others, besides the *general* properties possessed by all matter.

A **body** is a separate limited portion of matter, *e.g.* a penny, a chair, a drop of oil, an air-bubble, etc.

Bodies, even when made of the same substance, may contain different quantities of matter. The word *mass* is used to indicate *the quantity of matter* in a body. Bodies may also differ in the amount of space they occupy. The space which a body occupies is called its *volume.*

A cannon-ball and a bullet are two different bodies that may be made of the same substance. Their masses, however, are different, and so are their volumes. Bodies may have the same volume, but different masses. A ball of dough equal in volume to the cannon-ball has a less mass—that is, contains a smaller quantity of matter. An equal volume of air would have a smaller mass than either. The masses of bodies are often compared by comparing their weights, since weight increases or diminishes just in proportion to the increase or decrease of mass at any one place on the earth. This is expressed by saying that *the masses of bodies are in proportion to, or vary as, their weight.* But *mass* is not the same as *weight.* The mass of a body is the quantity of matter in a body; the weight is the force with which the earth attracts a body. If the earth had less attractive force, a body would have less weight, but its mass or quantity of matter would remain the same (see also par. 17).

2. The Structure of Matter.—All bodies possess the property of *divisibility*, that is, they can be subdivided into very small parts more or less easily by such mechanical means as pounding, filing, etc. Gold can be beaten out into leaves so thin that 300,000 leaves are only an inch thick, while platinum wire has been obtained $\frac{1}{3,000,000}$ of an inch in diameter. In chemistry, however, it is necessary to consider particles or very small parts much smaller than any that can be obtained by mechanical means. These very small parts are called *molecules* (Lat. *molecula*, a little mass). A molecule may

be defined as "the smallest part of a substance that possesses the properties distinguishing that substance from others." All matter has a *molecular structure.*

Now, the molecular structure of matter is not continuous, as there are in all cases spaces between the molecules called "pores," and these spaces may be occupied by other matter, or allow other matter to pass through. In some bodies, as sponge, pumice-stone, and blotting-paper, the pores are large enough to be seen; but in other bodies, as iron, gold, etc., the pores are too minute to be detected by ordinary means. By squeezing and hammering a hollow globe of silver filled with water, the liquid has been made to ooze through. A mixture of 27 parts of water and 23 parts of alcohol by volume occupies 48·8 parts, showing that some molecules of one liquid have found spaces between those of the other.

In ordinary language, however, only those bodies are said to be *porous* that have "sensible pores."

The property of *porosity* is made use of in the process of filtration. A filter is any body with pores large enough to let a liquid pass through without any extra pressure, but small enough to keep back the small solid particles suspended in the liquid. Unsized paper, fine muslin, charcoal, or layers of sand may be used as filters. Deep well water is clear because it has been filtered through porous rock.

FIG. 2.—Method of filtering to remove matter in suspension.

Experiment 2. — Obtain some muddy water, or water with any kind of small solid particles in suspension. Now take a circular piece of the unsized paper, called filter-paper, and, after folding it twice, open it out into a cone so that three folds of the paper are on one side and one fold on the other. Now place it in a glass funnel, and pour the liquid on the filter

down a glass rod. All the solid particles in suspension are removed and left behind on the filter-paper, while the liquid runs through the pores of the paper and comes out clear. The clear liquid that comes through a filter-paper is called the *filtrate.* It must be carefully noted that a filter will not keep back matter that is dissolved in a liquid. Salt water when passed through a filter-paper still remains salt, and ink so treated still keeps its colour.

3. **The Three States of Matter.**—Substances and bodies exist in three forms (states), known as solids, liquids, and gases. Thus water is a liquid at ordinary temperatures. On being cooled it may be made to pass into ice, a solid; on being heated it may be made to pass into an invisible state called steam. Real steam is invisible. It has partially condensed into very fine water-particles when it becomes visible as a white cloud.

Both liquids and gases are included under the term *fluids* (Lat. *fluo*, to flow), as they can be made to flow from one vessel to another. Hence the states of aggregation in which bodies exist may be thus represented:

Bodies
- Solids
- Fluids
  - Liquids
  - Gases

We now proceed to define and distinguish each state of matter.

A **solid** *is a body that has a definite shape and that offers resistance to change of shape.* Resistance to change of shape is termed *rigidity.* Solids, therefore, may be defined as bodies that possess rigidity to a considerable extent.

A **fluid** is a body that offers little or no resistance to change of shape, and that flows more or less easily.

A **liquid** *is a practically incompressible fluid whose free surface is horizontal.*

A perfect liquid has no rigidity and offers no appreciable resistance to change of shape. Many liquids, however, offer some resistance to flow, and are said to be *viscous* or to possess viscosity. Such liquids as honey, treacle, and pitch have

considerable viscosity, while alcohol and ether are more mobile than water. A substance like sealing-wax may be regarded as a semi-solid or as a very viscous fluid. A stick of sealing-wax supported at its two ends only gradually flows, as it slowly bends under its own weight. On heating, its liquid condition, as shown by its increased power to flow, becomes more marked. A soft solid like jelly undergoes its change of shape under the action of a force, all at once.

A **gas** *is a very compressible fluid, and any portion, however small, will spread itself out into any space.*

Gases take not only the shape of the containing vessel, as liquids do, but the size of the containing vessel, however large this may be.

Experiment 3.—Obtain in different vessels some softened pitch, some treacle, some water, and some ether. Compare their consistency or degree of viscosity by shaking each vessel and by noting which flows least readily. The pitch will be seen to be the most viscous, and the ether the most mobile.

Change of State.—The same substance or kind of matter can exist in all three states. As already noted, ice, liquid water, and true steam are only different states or forms of the same substance. Solid sulphur may be turned by heat into a yellow liquid. On continuing the supply of heat, the liquid darkens in colour and then gives off a gas that will burn.

The transition from one state to another is sometimes gradual and sometimes sudden.

Experiment 4.—Obtain a few crystals of the dark solid substance called iodine, and place these in a clean dry flask. Now heat the flask over the flame of a Bunsen burner, and notice the bright purple gas or vapour[1] which soon fills the flask. On allowing the vapour to cool, minute solid crystals form on the sides of the vessel, the intermediate state being unnoticeable.

Even solid metals like lead and iron are gradually changed into liquids by the heat of a furnace, and at very high temperatures they are converted into gases. Gaseous iron is known to exist in the sun.

[1] A vapour is the gas of a substance that is a solid or liquid at ordinary temperatures.

Change of volume usually accompanies change of state. With few exceptions, a liquid occupies a greater volume than the solid from which it is derived, and a gas always occupies a greater volume than the liquid from which it was formed.

4. **Cohesion.**—In many bodies force is necessary in order to draw its parts asunder. The force that thus holds the small particles or molecules of a body together is spoken of as the force of *cohesion*. If we break a stone or other solid body into parts, we overcome cohesion. On trying to press together the parts so as to make them unite again into one body, we usually fail, for we cannot get the parts sufficiently close to make them cohere. Cohesion acts only when the particles are at insensible distances apart. It is spoken of as a molecular force.

As just stated, ordinary pressure usually fails to get the parts sufficiently close to make them cohere. A piece of lead cut in two may, however, be made to unite again by pressing strongly together the two freshly cut surfaces. But two pieces of iron cannot be made to cohere thus, unless they are softened by heat and then hammered together. In the process of welding cohesion is thus brought into action.

In general, cohesion is most powerful among the particles of solid bodies. It acts weakly, but to some extent in liquids, as is evident by the formation of drops. It is entirely wanting in elastic fluids, as air and other gases, for in them the molecules are moving freely and rapidly in all directions. The most powerful influence that opposes the force of cohesion is heat, as is shown in the change of a solid to a liquid, and of a liquid to a gas.

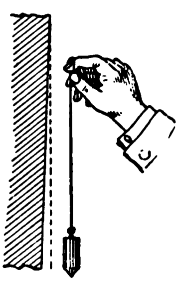


FIG. 3.—Action of gravity on a plummet: Finding the vertical.

5. **Gravitation and Weight.**—A body which lies upon the hand exerts a downward pressure upon it. If the hand be quickly removed, the body falls straight down to the ground, and force is required to raise it again. If the body be hung at the end of a string, the string is made to hang directly downwards. To account for these facts, we

say that the earth draws or attracts the body with a force that is directed towards its centre. The force which draws all bodies on or near the surface of the earth towards its centre is called *terrestrial gravity*, or simply *gravity*. The direction in which the force acts is called *vertical*, and a direction at right angles to the vertical is called *horizontal*.

The pressure exerted by any body in consequence of the gravitational force of the earth is called the *weight* of the body. Moreover, if we break a body into very small parts, each of these small parts exerts a downward pressure and falls vertically, if free to do so. We therefore conclude that gravity acts upon the smallest particles or molecules of a body, and that every molecule has weight.

Since weight, therefore, is a general property of matter and inseparable from it on the earth, we use weight as a measure of the mass or quantity of matter in a body. Hence we interpret *increase of weight as an addition of matter, and decrease of weight as a loss of matter*.

6. **Indestructibility of Matter.**—Careful observations and experiments have proved that, though matter may be made to undergo many changes, yet there is never any destruction or annihilation of matter. Nor is there ever any creation of matter, *i.e.* any formation of matter out of nothing. The quantity of matter in the universe is constant and unchangeable. The truth thus stated is known as "the law of the Conservation of Matter."

The following experiments illustrate the property of the indestructibility of matter.

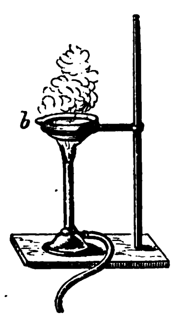


FIG. 4.—Evaporation to recover dissolved matter.

Experiment 5.—Add 1 oz. of salt to 6 ozs. of water contained in a beaker, and stir. The salt passes out of sight, but it is not lost. On weighing the solution, it is found to be just 7 ozs. If the water be now poured into a porcelain basin and heated, it soon evaporates, and the ounce of salt may be recovered. A solid substance in solution may always be thus recovered by the process of evaporation, though not by filtration.

Experiment 6.—Place a piece of ice in a flask. Cork the flask and

counterpoise it on a balance. Heat the ice gently. It changes into a liquid, but though there is a change of state, there is no loss of matter, for the weight remains the same.

Experiment 7.—When water is "boiled away" there is no loss of matter. It only passes into an invisible vapour. If we condense this vapour, and collect the water thus recovered in the liquid form, the weight will be the same as before. The experiment may be thus arranged:

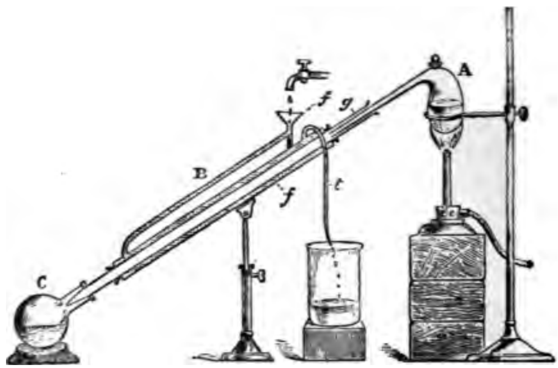


FIG. 5.—Apparatus for condensing the steam given off by boiling water, *i.e.* for obtaining distilled water.

A is a stoppered retort, into which a weighed quantity of clean water may be placed. Its neck passes into the condenser B. This consists of an inner tube, *g*, into which the neck of the retort passes, and a wider outer tube, *f*, surrounding the inner tube, but having no communication with it. The inner tube passes on into the receiving flask C. On heating the water in the retort, the steam given off passes into the smaller inner tube of the condenser. Here it is cooled by the stream of cold water passing through the wider outer tube or jacket. This cold stream cannot mix with the steam of the inner tube, but flows away by the small tube *t* that passes from the wide tube of the condenser. The condensed steam or distilled water drops into the receiver C. The loss of weight of water from the retort A is just represented by the gain of weight of the receiver C. There is therefore no loss of matter, only a change of form, when water is boiled away.

The water collected in C is pure distilled water. If we placed in A water with salt or sugar dissolved in it, the water collected in C would still be pure, all the dissolved matter being left behind during the process of distillation. Distilled water is chemically pure. It is quite colourless, but insipid. To make it suitable for drinking, air must be passed into it, for the dissolved air causes it to lose its insipid taste.

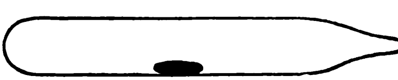


FIG. 6.

Experiment 8.—Take a small quantity of red phosphorus, and place it in a flask or a piece of hard glass tubing (Fig. 6). Close the vessel, and

weigh it with its contents—phosphorus and air. On heating the vessel, the phosphorus ignites, and a white powder is seen as the result of the burning. But on weighing again there is no change of weight, and therefore neither loss nor increase of matter.

As we shall learn more fully in a later chapter, in all cases of burning, the substance burnt is not destroyed, but merely enters into combination with the oxygen of the air to form other kinds of matter—often invisible gases. But the weight of the new substance formed is always equal to the weight of the substance burnt *plus* the weight of the oxygen taken from the air (see par. 94). Even in the growth of a tree, we know that all the additional matter that it gains comes from either the soil or the air, and that these lose just as much as the tree gains. In fact, in no process whatever, either natural or artificial, is there either gain or loss of matter.

CHAPTER II.

UNITS OF MEASUREMENT.

7. **Measurement.**—The process of measurement consists in comparing the quantity to be measured with a known quantity of the same kind called the standard, or *unit*, so as to find the numerical relation between the two quantities. Every measurement is thus expressed by means of a number and a word naming the unit employed, *e.g.* 12 yards, 25 grams.

Among the most important kinds of quantity to be measured are *length*, *area*, *volume*, *mass*, *time*, and *angle*. Unfortunately, for the first four of these magnitudes a different system of units is employed in English-speaking countries from that in use on the continent.

The British Units of Length, Area, and Volume.—The British standard unit of *length* is the *imperial yard*. It may be defined as the distance between two marks on a metal bar preserved in the Standard Office at London, the distance being measured when the bar has a temperature of 62° F. Any of the subdivisions or multiples of the yard may be used as the unit when convenient.

The British unit of *area* or *surface* is derived from the linear unit, and called the *square yard*. It is the area of a square each of whose sides is a yard.

The British unit of *volume* is a cubic yard, that is, the volume of a cube the length of whose edges is one yard.

Another unit of volume is used as a measure of *capacity* for liquids and dry goods, called the *gallon*. It may be defined as the volume occupied by 10 lbs. (avoir.) of distilled water at 62° F. Its subdivisions are termed quarts and pints. It will be easily seen that "a pint of pure water weighs a pound and a quarter." ($\frac{1}{20}$ of a pint is called a *fluid ounce*.)

It should be noted that there is no simple relation between this last unit of volume and the unit of length, for the gallon contains 277·274 cubic inches.

The British unit of *mass* is called the imperial standard pound, or *pound avoirdupois*. Exact copies of this can be obtained, and exact multiples or subdivisions are then made. The names of these are given in the table called Avoirdupois Weight. The measurement of mass is usually called "weighing," and the standard masses used are called "weights." But, as already noted, mass is not the same kind of quantity as weight. The *mass* of a body is the quantity of matter contained in the body; the *weight* of a body is the force exerted upon it by the attraction of the earth (gravity). But because the weights of bodies are exactly proportional to their masses at any one place on the earth's surface (weight increasing or diminishing as mass increases or diminishes), we regard masses as equal when their weights are equal, and often use the word *weight* in place of *mass*. Hence also the pound avoirdupois is often called the unit of *weight*.

8. **The Metric System.**—The Metric system of units is a decimal system, in which the various units of measurement are all connected with the standard unit of length called the *metre*, *i.e.* the standard units of area, volume, capacity, and weight are in the metric system all derived from the metre.

The multiples of each unit in the metric system contain that unit either 10, 100, or 1000 times; while the parts or submultiples of each unit are $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ part of the unit. The decimal multiples of a unit are indicated by the *Greek* prefixes—

deca (10) *hecto* (100) *kilo* (1000);

while the decimal parts of a unit are denoted by the *Latin* prefixes—

deci ($\frac{1}{10}$ or 0·1) *centi* ($\frac{1}{100}$ or 0·01) *milli* ($\frac{1}{1000}$ or 0·001).

The metric standard unit of length is the metre. It can be defined as "the distance between the ends of a rod of platinum made by Borda, and preserved at Paris, the rod being at the temperature of melting ice." Exact copies of this have been

distributed for general use. The advantage of the metre as a unit of length is not that the metre itself is a better unit than the yard, but that its multiples and parts are more easily found and calculated. Thus—

10 millimetres	make	1 centimetre (cm.)
10 centimetres	,,	1 decimetre (dm.)
10 decimetres	,,	**1 metre** (m.)
10 metres	,,	1 decametre (Dm.)
10 decametres	,,	1 hectometre (hm.)
10 hectometres	,,	1 kilometre (km.)

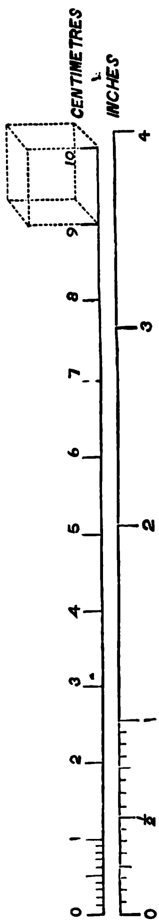


FIG. 7.

The abbreviations used to denote the various measures are indicated in brackets. The metre is about 39·37 inches. Fig. 7 shows a decimetre and its subdivisions side by side with a scale of inches and fractions of an inch. It may be seen that a decimetre is scarcely 4 inches long, that a centimetre is a little more than $\frac{3}{8}$ inch (about $\frac{2}{5}$ inch), and that a millimetre (mm.) is about $\frac{1}{25}$ inch.

The metric unit of area is a square metre, that is, a square each side of which is a unit of length, *i.e.* a metre. Hence the table of square measure can be obtained by squaring each lineal unit. Thus 100 sq. mm. equal 1 sq. cm.; 100 sq. cm. make 1 sq. dm.; and so on.

The metric unit of volume is a cubic metre, that is, a cube the length, breadth, and height of which are each one metre. Hence a table of cubic measure can be obtained by cubing each lineal unit. Thus—

1000 cubic millimetres (c.mm)	make	1 cubic centimetre (c. cm.)
1000 cubic centimetres	,,	1 cubic decimetre (c. dm.)
1000 cubic decimetres	,,	1 cubic metre (cb. m.)

The *metric unit of capacity* for fluids and dry goods is the *litre*. Its multiples and subdivisions are named in the same way as those of the lineal metre, so that the names, not being expressed in words derived from the measure of length, indicate

that each unit is but *ten* times greater than the next smaller one. The following is the metric table of capacity :—

10 millilitres (ml.)	= 1 centilitre.
10 centilitres (cl.)	= 1 decilitre.
10 decilitres (dl.)	= **1 litre.**
10 litres (lit.)	= 1 dekalitre.
10 dekalitres (Dl.)	= 1 hectolitre.
10 hectolitres (hl.)	= 1 kilolitre (kl.).

Now, a litre is equal in volume to a cubic decimetre, and as a cubic decimetre contains 1000 cubic centimetres, it is easy to express the value of any measure of capacity in cubic centimetres.

The *metric unit of mass* or *weight* (see par. 7) is the weight of a cubic centimetre of pure water when at its greatest density, and is called a *gramme* (or *gram*). From it the larger and smaller weights and their names are derived in the same way as in the metric table of length.

10 milligrams (mg.)	= 1 centigram.
10 centigrams (cg.)	= 1 decigram.
10 decigrams (dg.)	= 1 **gram.**
10 grams (grm.)	= 1 dekagram.
10 dekagrams (Dg.)	= 1 hectogram.
10 hectograms (hg.)	= 1 kilogram (kg.).

It is just as easy to pass from one weight denomination to another as in the metric linear measure. Thus 7358·42 grams = 7·35842 kilograms = 7 kg. 3 hg. 5 Dg. 8 grm. 4 dg. 2 cg.

Our British system of weights is connected with certain volumes of water in a complicated way, but in the French the relation between a volume of water and its weight is quite simple. *One gram is the weight of one cubic centimetre of pure water at* 4° *C.* (The reason for mentioning this temperature will be understood after reading par. 60.) In a litre there are 1000 c.c., and therefore 1000 grams, that is, a kilogram. This connection between the units of weight and volume in the metric system is of great service, for the weight of any quantity of water can be at once written down on finding its volume, or *vice versâ*.

The *gram* is the ordinary unit of weight for experiments in the laboratory; it is equal to about $15\frac{1}{2}$ grains, or $\frac{1}{28}$ oz. A

threepenny piece weighs about $1\frac{1}{2}$ gram. The unit of weight in common life is the kilogram, or *kilo*, which is nearly $2\frac{1}{4}$ lbs. Half a kilogram, or 500 grams, is thus a little more than a pound.

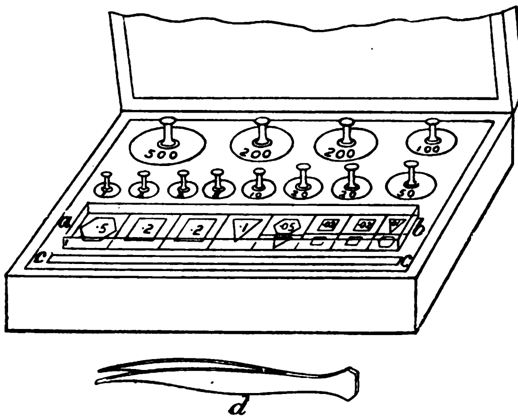


FIG. 8.—Box of metric weights : (*d*) forceps for picking up the weights. The numbers indicate grams and decimals of a gram.

9. **Connection between British and Metric Units.**—To connect the Metric system of weights and measures with the British system, the following two equivalents must be known:—

1 metre = 39·37079 inches.
1 gallon = 277·274 cubic inches.

As rough equivalents, the following are useful to remember:—

1 mm. = $\frac{1}{25}$ in.	1 litre = $1\frac{3}{4}$ pint	1 inch = $2\frac{1}{2}$ cm. or 25 mm.
1 cm. = $\frac{2}{5}$ in.	1 gram = $\frac{1}{28}$ oz.	1 pint = $\frac{4}{7}$ litre.
1 metre = $1\frac{1}{11}$ yd.	1 kg. = $2\frac{1}{4}$ lbs.	1 oz. = $28\frac{1}{2}$ grams.

10. **Units of Space and Mass arbitrary.**—Both in the Metric and the British systems the units for measuring space and mass (weight) are quite arbitrary or empirical, for they are not derived from any natural object. It was at first thought that the metre was a natural unit, as it was supposed to be equal to the *one ten-millionth part of the distance between the north pole and the equator* measured on the circle of longitude passing through Paris. More accurate measurements of this

quadrant show that a distance somewhat too small was taken in forming the metre, and as the length of the standard metal rod has not been altered, the metre is no longer the natural unit it was supposed to be. The actual length of this quadrant is 10,007,400 metres.

11. **Advantages of the Metric System.**

(1) The various tables of measures and weights are very simple and easy to remember.

(2) The process of *reduction* becomes quite simple, as it only consists of multiplying or dividing by 10 or some power of 10.

(3) The "compound" rules disappear.

(4) The relative sizes of the different units are easily understood, and there is only a simple relation between the unit of volume and the unit of mass (1 c.c. of water weighs 1 grm.).

It may, however, be remarked that as the foot contains 12 inches, it can be exactly divided into halves, quarters, thirds, and sixths, while the number 10 is exactly divisible only by 2 and 5.

12. **The Unit of Time.**—The unit of time adopted in civilized countries is the *mean solar second.* This may be regarded as a natural unit, as it is the $\frac{1}{86400}$ part of a mean solar day, and depends on the rotation of the earth. A *mean solar day* is the average interval of time that elapses between two successive passages of the sun across a meridian (see par. 263). The Table of Time may be thus given:

60 seconds (sec.)	make	1 minute.
60 minutes (min.)	,,	1 hour.
24 hours (hr.)	,,	1 day.

Clocks and watches moved by a pendulum or by a coiled spring are made and regulated so as to keep mean solar time.

A simple pendulum is merely a small weight suspended by a fine flexible string from a fixed point, so that it can vibrate or swing backwards and forwards.

Experiment 9.—To make a "seconds pendulum," *i.e.* a pendulum which swings from its highest point on one side to its highest point on the other side in a second, we need only a length of fine cotton and a small lead

sphere into which a hook is fastened. Clamp the thread tightly between two fixed blocks of wood so as to keep it always the same length. Set it vibrating in a small arc of about 3 inches, and find the time of 30 or 40 vibrations. On dividing this time by 30 or 40, as the case may be, we get the time of one vibration. If the pendulum vibrates more than once a second, lengthen it; if it is too slow, shorten it. On getting the right length for a swing in one second, it will be found to be a little more than 39 inches, or nearly 99½ cms.

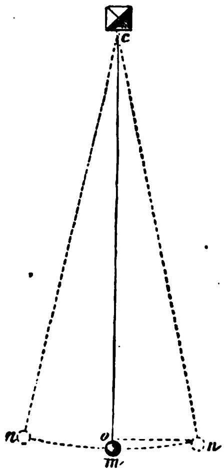


FIG. 9.—Pendulum swinging through arc *pn*.

The exact length of a pendulum vibrating seconds in London is 39·1393 inches, or 99·413 cms. This fact would afford the means of recovering the standard yard or standard metre, should either be destroyed.

13. **Angular Measurement.**—Euclid gives the following definition of a right angle: "When a straight line standing on another straight line makes the adjacent angles equal to one another, each of the angles is called a right angle, and the straight line which stands on the other is called a perpendicular to it." Notice that "perpendicular" does not always mean upright, but making equal angles on both or all sides. We find it convenient, for the purposes of angular measurement, to divide the right angle into smaller parts. Each right angle is accordingly divided into 90 equal parts, and each of these parts is called a *degree*. Each degree is again divided into 60 equal parts, one of these parts being termed a *minute*; and if a minute be subdivided into 60 equal parts, each of these parts is termed a *second*. Symbols are used to denote these terms: thus 28° 19′ 47″ signifies 28 degrees 19 minutes 47 seconds. (Do not confuse these with minutes and seconds of time.) There are four right angles in every complete circle; and so, for the convenience of measuring angles, we can divide

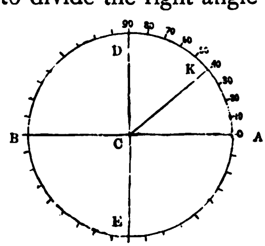


FIG. 10.—Graduated circle.

the circumference of a circle into 360 divisions, each of which is called a degree. Such a divided circle is called a *graduated circle*, and the angle whose measurement is so many degrees is the angle included between two straight lines drawn from the centre of the circle to the two marks on the circumference which include the proper number of divisions or degrees.

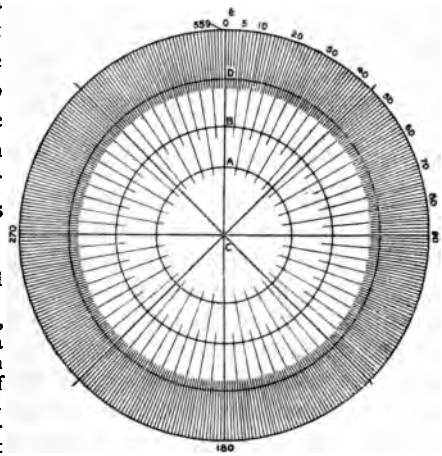


FIG. 11.—Concentric graduated circles. The two outer ones divided into degrees.

It should be noted that a degree is an angle, and not an arc of a circle, though the arcs on a divided circle are often taken as the measure of the number of degrees. For it is shown in geometry that the angles at the centre of a circle are proportional to the arcs on which they stand, and so there are no more degrees in the greatest circle than in the least. Two concentric arcs count as many degrees in the one as in the other when they subtend the same angle at the centre. A degree, then, may be subtended by an arc of any length, but the arc is always the 360th part of a circle. For astronomical purposes the divisions are made to a much greater extent than on an ordinary graduated circle. An instrument called a meridian circle may have its consecutive divisions only 2′ (two minutes) apart, so that the circumference then contains 360 × 30 = 10,800 divisions.

CHAPTER III.

GRAVITATION AND SPECIFIC GRAVITY.

14. **Gravitation.**—We have already spoken of an invisible force of attraction exerted by the earth on all bodies, which gives rise to the *weight* of a body which is supported, and to the *fall* of a body that is unsupported. This attraction is called the attraction of gravitation or gravity (Lat. *gravitas*, weight). Sir Isaac Newton pointed out that this attraction not only takes place between the earth and bodies near it, but that all bodies in the universe attract one another, so that the force of gravitation is universal. The mutual attraction of the earth and the bodies on or near its surface is only a particular case of this universal attraction, this particular case being called terrestrial gravity. The general law is—

Every particle of matter in the universe attracts every other particle with a force whose direction is that of the line joining the two, and whose magnitude is directly as the product of their masses, and inversely as the square of their distance from each other.

15. If every particle attract every other particle, why do we not see two suspended balls come together? The reason is that the attractive force of the earth on the balls is so very great compared with that of the balls on each other that this latter is hardly perceptible without special apparatus to detect it. But if only these two balls existed in the universe they would begin to approach one another, and would finally meet. This leads us to the first law of gravitation—*The force of gravitation varies directly according to the product of two masses.* This is plain; for if every particle exert its attractive influence, the more particles a body contains the greater will be the attraction. A body which contains twice as much matter as another is attracted or drawn towards the centre of the earth with twice the force—that is, it will have twice the weight of the other; if its mass be five times as great, then it will be attracted with five times the force, that is, it will have five times the weight of the other. Hence we see how it is that the earth exerts such an overwhelming attractive force as to draw all bodies

towards its centre, its mass being so very great compared with that of any single body on its surface. If the mass of the earth were only half what it is, its attractive force would only be half as great; on the other hand, if the mass of the earth were twice what it is, then the attraction of gravitation at its surface would be twice as great. It may be said that such things as smoke, vapour, and balloons filled with light gas ascend. They do this simply because they are lighter, bulk for bulk, than air, and therefore the earth attracts the air with greater force than it attracts the lighter bodies, and the heavier air pushes them up until they reach a layer of air of the same density as themselves. For the same reason a piece of cork, when held under water and then released, rises to the top.

The second part of the law of gravitation teaches us that *the force of gravity varies inversely as the square of the distance.* This means that if for any two bodies the distance be doubled, the attraction between them is diminished four times; if the distance be trebled, the force of attraction is diminished nine times; if the distance be increased ten times, the force of attraction is diminished one hundred times; and so on.

$$2^2 = 4, \text{ and invert} = \tfrac{1}{4};\ 3^2 = 9, \text{ and invert} = \tfrac{1}{9};$$
$$10^2 = 100, \text{ and invert} = \tfrac{1}{100}.$$

Since the attractive force of the earth must be calculated from its centre, and since the equatorial diameter of the earth is greater than the polar diameter, the force of gravity at the poles must be greater than at the equator, bodies there being at a less distance from the centre.

Thus, in the figure, OE is greater than OC, and still

FIG. 12.—Showing polar radius PO less than equatorial radius EO or E'O, also showing direction of vertical lines *d*O, *a*O, *b*O, and CO.

greater than OP. There is also another reason why the attractive force is greater at the poles, as will be shortly explained.

16. The direction taken by a body falling freely towards the earth is called the *vertical*, and the vertical lines at different points of the earth's surface when prolonged meet at the centre (see Fig. 12). But, owing to the great distance of the surface from the centre, these verticals may be considered parallel for points situated close together, as at *a* and *b*. But the further the points are apart the more do the lines depart from being parallel, till, as the earth is spherical, at points exactly opposite the two lines are in inverted positions. Places on the surface of the earth diametrically opposite each other are called antipodes (Gr. *anti*, against; and *pous*, *podos*, foot).

It is a consequence of the mode in which gravitation acts that all bodies free to fall, fall to the earth with *equal velocity*, for if gravity attracts a ten-pound weight with ten times the force that it pulls at a one-pound weight, attraction being proportional to mass, yet it has ten times as much matter to move. It was at one time thought that a ten-pound weight would fall to the ground ten times as fast as a one-pound weight, that two bricks fastened together would fall twice as fast as one of the same size. But the Italian philosopher Galileo took bodies of different weight and of about the same density to the top of the tower at Pisa, and showed that they reached the ground at the same time as nearly as possible when let fall together. It is true that if we take a feather and a sovereign and let them fall from a height together, the sovereign reaches the ground first. But this is due to the greater resistance of the air on the feather, for it is much larger than the coin compared with its weight. If, however, we take a tall jar and exhaust the air by means of an air-pump, and then contrive to drop the coin and the feather from the top of the jar at the same time, they will reach the bottom at the same time.

Experiment 10.—Place on a penny a circular disc of stout paper a little less in diameter, and let them fall together. They reach the ground at the same instant, for the penny protects the paper from the resistance of the air. Separately the penny reaches the ground before the paper disc.

17. **Weight and Mass.**—In popular language and thought the ideas connected with the two words *mass* and *weight* are not always clear and distinct. The *mass* of a body is the

quantity of matter contained in the body; the *weight* of a body is the force of the earth's attraction on the body. When we speak, therefore, of steam exerting a pressure of 40 lbs. on the square inch, we are using the word *pound* as a unit of *force;* but when we talk of buying so many pounds of butter, we are using the word *pound* as a unit of *mass*. This double use of such words as pounds, tons, grams, etc., is due to the fact that at any place the masses of bodies are proportional to their weights, so that *bodies that have equal weights are of equal mass*, and *vice versâ* (par. 1). Hence *we usually compare the masses of bodies by weighing them at the same place.*

The essential difference between weight and mass must not, however, be forgotten. It is brought out not only in the definitions given, but also by the fact that if a piece of lead or other matter be taken to places at different latitudes on the earth's surface, its weight or gravitating force towards the earth varies, but its mass remains the same. This variation would be shown by a graduated spring balance which measures the force directly exerted on a spring. It would not be shown by an ordinary pair of scales and weights, since any alteration in the gravitating force would affect the bodies used as "weights" to the same extent that it would affect the piece of lead, so that the weight which balances the lead in one place would balance it in another.

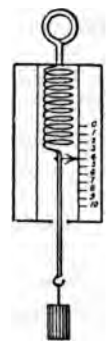


FIG. 13.—Spring balance.

Bodies weigh most on a spring balance at the poles and diminish in weight up to the equator for two reasons.

(1) The earth is somewhat flattened at the poles, and bulges at the equator. Hence a body is nearer the centre at the poles than in other latitudes, and the nearer a body is to the centre of the earth, the greater is the earth's attractive force.

(2) The earth is rotating on its own axis once a day, and it is plain that the nearer a place is to the equator the greater is the circle of rotation and the higher the speed of rotation. Now, the effect of this rotation is to produce a tendency in a body on the earth's surface to fly off at a tangent,

and thus to counteract some of the earth's gravitative force. The sum of these two effects is to reduce the weight or gravitative force exerted by the earth $\frac{1}{194}$ part in passing from the pole to the equator, so that a body that pulled the spring of a balance to indicate 194 lbs. of force at the pole, would only pull it far enough to indicate 193 lbs. of force at the equator.

18. We now see that, according to strict scientific use, the *weight* of a body is the downward pressure exerted by that body on its support owing to the earth's pull upon the body. This weight is expressed in pounds or grams according to the system of units we employ. Now, it is often convenient to know *the ratio or proportion which the weight of a body bears to the weight of an equal bulk of pure water.* This relative or comparative weight is usually called the **specific gravity** of the body. As a ratio can be put in the form of a fraction, we get—

$$\text{Specific gravity} = \frac{\text{weight of any volume of a substance}}{\text{weight of equal volume of water}}$$

or, since the masses of bodies at any one place are proportional to their weights, we may also say—

$$\text{Specific gravity} = \frac{\text{mass of any volume of a substance}}{\text{mass of an equal volume of water}}$$

Note carefully that the value of this ratio or fraction, found by dividing the numerator by the denominator, will be an *abstract number* only, not a number of pounds or grams.

Example.—A small cube of lead measuring 2 cms. each way is found to weigh 91·2 grms. Find its specific gravity.

Solution.—The volume or bulk of the cube will be $2 \times 2 \times 2 = 8$ c.cms. Now, a cubic centimetre of water weighs 1 grm., therefore the weight of a volume of water equal to the lead cube will be 8 grms.

$$\text{Therefore specific gravity of the lead} = \frac{91{\cdot}2 \text{ grms.}}{8 \text{ grms.}} = 11{\cdot}4$$

19. **Determination of the Specific Gravity of Liquids.**—As liquids are easily measured and weighed, it is easy to find the two terms of the ratio that express the specific gravity of a substance. Thus we might fill a glass or tube with the liquid whose specific gravity is required, and then fill another equal flask with water. On finding the weights of each of these, we

should then be able to obtain the specific gravity required. It is better, however, to use a flask with a mark upon the neck at a certain height, or a small flask fitted with a glass stopper, through which a narrow passage has been left (Fig. 14, A, B). With the former we fill up to the mark on the neck, first with the liquid and then with water, having previously counterpoised the flask. With the latter, we fill the vessel and insert the stopper. Any excess of liquid passes out through the stopper and is wiped off.

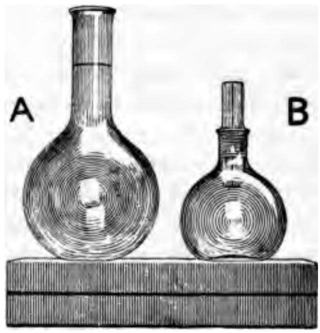


FIG. 14.
(From Watson's "Elementary Practical Physics.")

Experiment 11.—Suppose we are required to find the specific gravity of sulphuric acid. (i.) Weigh the marked flask. Let the counterpoise of the flask be 230 grms. (ii.) Fill the bottle with water up to the mark and weigh again. Let the result be 850 grms. (iii.) Empty the bottle, and after drying fill it with sulphuric acid up to the mark and weigh again. Let the result be 1270 grms.

We learn from these results (*a*) that the weight of the volume of water taken = 850 grms. – 230 grms. = 620 grms.; (*b*) that the weight of an equal volume of sulphuric acid weighs 1370 grms. – 230 grms. = 1140 grms.

Hence the specific gravity of the sulphuric acid $= \frac{1140}{620} = 1 \cdot 84$

The specific gravity of any other liquid can be found in a similar way, and the same result will be obtained whether we use metric weights or English weights. Small metric weights are, however, more easily obtained.

20. **Specific Gravity of Solids.**—We may find the specific gravity of a solid, after weighing it in air, by placing it in a *graduated* vessel and noticing how much water it displaces. Thus if a solid be placed in such a vessel, and if it displaces 12 c.cms. of water, we know that its volume is 12 c.cms., and that the weight of a volume of water equal to it is 12 grms. If, then, the solid weighs 42 grms. in air, its specific gravity will be $\frac{42}{12} = 3 \cdot 5$. This method, however, is not the usual method.

21. **The Principle of Archimedes.**—Before explaining the usual method of finding the specific gravity of a solid, we must

first state and prove an important truth called after the name of its discoverer, the Principle of Archimedes. It is a matter of common experience that if we lower a stone attached to a string into water, its weight or downward pull becomes less. If we place a cork in water it floats, and if we push it to the bottom of a vessel of water and release it there, it rises at once to the surface, though the force of gravity is pulling it downwards. We conclude, therefore, that when a body is immersed in a fluid, an upward force is exerted by the fluid on the immersed body. This upward force is sometimes called the *buoyancy* of the fluid, and its amount is given by the principle of Archimedes, which states, *A solid immersed in a fluid loses an amount of weight equal to the weight of the fluid that it displaces.*

We may express this truth in another way by saying, "A body immersed in a fluid is buoyed up by a force equal in amount to the weight of the fluid displaced."

When, therefore, the body is entirely immersed in the fluid

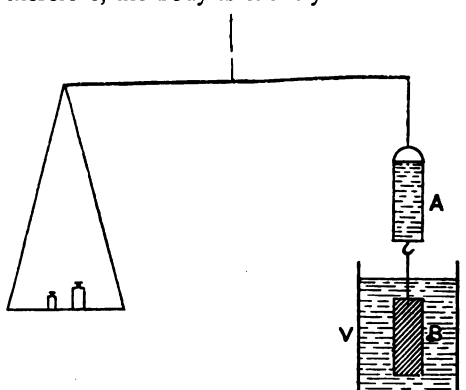


FIG. 15.—Apparatus to prove the principle of Archimedes. A, hollow cylinder; B, solid cylinder; V, vessel of water.

the loss of weight is evidently equal to the weight of its own bulk of water.

Experiment 12. —Take a small pail or hollow cylinder, A, and procure a solid cylinder of brass or other metal, B, which will just fill A. Hang B below A, and attach both to one scale of a balance. Add weights to the

other scale-pan to balance the two cylinders. Now bring a vessel of water under the solid cylinder so as to immerse it. The weights in the opposite scale-pan are now too heavy, as B is buoyed up to a certain extent by the water. Pour water gently into the pail A until it is full, and notice that the arms of the balance again become horizontal as equilibrium is restored. This shows that the weight of the pailful of water just equals the loss of weight suffered by the solid cylinder in water, and as this pailful of water is exactly equal in bulk or volume to the solid cylinder, the experiment proves the principle of Archimedes stated above.

The expression "loss of weight" must not mislead the student, for there is no real loss, the weight of the vessel and water into which the solid is placed increasing by just the amount that appears to be lost. This may be shown by allowing the vessel V to rest on the scale-pan of another balance as the solid cylinder is being put into the water.

22. **Determination of the Specific Gravity of Solids.**—The principle of Archimedes indicates to us the best method of finding the specific gravity of solid bodies heavier than water. For—

$$\text{Specific gravity} = \frac{\text{weight of substance in air}}{\text{weight of an equal volume of water}}$$

and since a body entirely immersed in water loses an amount of weight equal to the weight of an equal volume of water, we can also say for such bodies that—

$$\text{Specific gravity} = \frac{\text{weight of body in air}}{\text{loss of weight in water}}$$

The loss of weight in water is found by subtracting its weight when in the water from its weight in the air. We may therefore say that specific gravity $= \frac{W}{W - W'}$, where W is the weight in air, and W′ the weight in water.

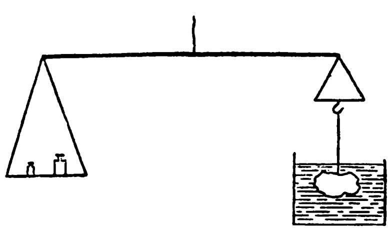


FIG. 16 —Method of finding the specific gravity of a solid.

Experiment 13.—Suppose we wish to find the specific gravity of a piece of iron. Weigh the iron in air, and suppose the weight is $15\frac{1}{2}$ ozs. Attach the iron to a fine thread, and weigh it in water. Let the weight in water be $13\frac{1}{2}$ ozs. Then by the principle of Archimedes the weight of an equal bulk of water and the loss of weight in water $= 15{\cdot}5 - 13{\cdot}5 = 2$ ozs. Therefore the specific gravity of the iron $= \frac{15{\cdot}5}{2} = 7{\cdot}75$.

Example.—An irregular piece of marble weighs in air 18·2 grms., and in water 11·7 grms. Find its specific gravity.

$18{\cdot}2 - 11{\cdot}7 = 6{\cdot}5$, *i.e.* the loss of weight in water is 6·5 grms.

therefore specific gravity $= \dfrac{18{\cdot}2}{6{\cdot}5} = 2{\cdot}8$

It is easy to see how the principle of Archimedes enables us to find the *volume* of any body whatever its shape, when we remember that one gram of water has a volume of one cubic centimetre. In the above example, the loss of weight in water, 6·5 grms., is the weight of an equal volume of water, *i.e.* of 6·5 c.cms. of water, and this also is the volume of the piece of marble.

The following table gives the specific gravities of some important solids and fluids:—

Specific Gravities of Solids.

Platinum	22·07	Marble	2·80
Gold	19·35	Aluminium	2·68
Lead	11·35	Rock-crystal	2·65
Silver	10·50	Salt	2·13
Copper	8·90	Coal	1·32
Iron	7·80	Ice	0·93
Heavy spar	4·43	White fir	0·57
Diamond	3·50	Cork	0·24

Specific Gravities of Liquids.

Mercury	13·60	Distilled water at 39° F.	1·00
Bromine	2·96	Distilled water at 32° F.	0·99
Sulphuric acid	1·84	Olive oil	0·91
Milk	1·03	Alcohol	0·80
Sea-water	1·02	Ether	0·72

With the help of such a table, we can readily find the *weight* of a body when we know its *volume*, or its *volume* when we know its *weight*. For since specific gravity is the number of times a body is heavier than an equal bulk of water, and water is the unit in the above table, the above numbers must give the weight of one cubic centimetre of each substance.

Example.—Find the weight of 625 c.cms. of silver.

The specific gravity of silver is 10·5, and therefore 1 c.cm. of silver weighs 10·5 grms. Therefore 625 c.cms. of silver weigh $625 \times 10{\cdot}5 = 6562{\cdot}5$ grms.

If English measures be used in any problem, it must be remembered that 1 cubic foot of water weighs 1000 ozs., or 62½ lbs. Thus a cubic foot ...n of specific gravity $7{\cdot}8 = 62\frac{1}{2} \times 7{\cdot}8 = 487{\cdot}5$ lbs.

23. **Why some Bodies sink and others float in a Liquid.** —A solid body will sink in a liquid if its weight is greater than its own volume of the liquid, because the upward pressure or buoyancy of the liquid is not then as great as the force of gravitation (the earth's attractive force) on the body. A solid body will float in a liquid if its weight is less than the weight of its bulk of the liquid, because the upward pressure or buoyancy of the liquid is greater than its weight, that is, greater than the downward force of gravity. Such a body, if pressed below the surface of the liquid, as a cork pressed to the bottom of a pail of water, rises to the surface on being released, though gravity is pulling it downwards, for the buoyant force of the liquid is then greater than gravity. A solid body will float anywhere entirely covered in a liquid when its weight is just equal to the weight of its own volume of the liquid, for then the buoyancy of the liquid and the earth's gravitative force just balance one another. A solution of salt and water may be made so strong that it will just cause an egg to float entirely immersed in the middle of the liquid.

A solid piece of iron sinks in water, because it is heavier bulk for bulk than an equal volume of water; it floats on the surface of mercury, because it is lighter bulk for bulk than mercury. The fraction of its volume that is immersed gives the volume of the mercury that is equal in weight to the weight of the whole piece of iron.

But a piece of iron can be made into a hollow vessel, so that when only partly immersed it displaces water equal to its own weight. The upward pressure being then equal to the weight of water displaced, the iron vessel floats and is able to carry a load. The weight of a vessel and its cargo is always equal to the weight of water that it displaces, *i.e.* to $62\frac{1}{2}$ lbs. multiplied by the number of cubic feet of water displaced.

The principle of Archimedes applies to gases as well as liquids, for the air exerts an upward pressure on all bodies in it equal to the weight of the volume of air displaced. This loss of weight in air is usually disregarded, as it is so small, but its action becomes apparent in the case of balloons. A balloon rises because the weight of the gas in it, the balloon itself and

all it carries, is less than the air which it displaces. When it ascends it passes into air that gets lighter and lighter, bulk for bulk, until at last the balloon displaces a weight of air exactly equal to its own. As the gas gradually escapes or is let out from the balloon it becomes less in bulk, and therefore heavier than the air it displaces. When this occurs the balloon descends.

24. **Density.**—The term *density*, when properly used, means "the mass or quantity of matter in a unit volume of a substance," *i.e.* since the mass of a body is usually measured by its weight, density may be defined as "the weight of a unit volume of a substance." Density, therefore, is expressed in "pounds per cubic foot," or in "grams per cubic centimetre," according to the system of units employed.

If we take a unit volume (1 c.cm.) of water, wood, iron, and lead, we find that they have different densities, since the weight of these equal volumes differ. This may arise from two causes: (*a*) because the individual particles of one substance may be more closely packed together than in another; (*b*) because the individual particles of one substance may contain more matter, that is, have a greater mass or weight, than those of another. We cannot alter the weight of the individual particles of any substance, but we can often force the particles of a body closer together by pressure. We should then be increasing the density of the body, for we should be increasing the weight of a unit volume of it. The wool in a pressed bundle is denser than that of the sheep's back, as its particles are closer together, and a unit volume of it is heavier.

The density of water is 1 gram per cubic centimetre; that of lead is 11·35 grams per cubic centimetre. The density of lead is therefore 11·35 times that of water, or lead is 11·35 times heavier than an equal bulk of water. The number expressing how many times a body is heavier than an equal bulk of water is the specific gravity of the body. Specific gravity is therefore the same as *relative* density.

In the metric system it will be noticed that the *number* used to express the density of a substance is the same number as that used to express its specific gravity, but the former is a

rete number (grams per cubic centimetre), and the latter an
act number, as it expresses a ratio only. Density and
fic gravity being numerically the same when the metric
m is employed, a Table of Specific Gravities serves also as
ɔle of Densities, and the word *density* comes to be used in
: of *specific gravity*.

CHAPTER IV.

MOTION, INERTIA, AND FORCE.

25. **Motion and Velocity.**—*Motion is change of position in relation to surrounding objects.* A point or a body is said to be in motion when it has different positions at different times. To understand the motion of a body, we must know the speed of the body and the direction or path in which it moves. At present we shall consider motion in a straight line, that is, *linear*, or, more correctly, *rectilinear* motion (Lat. *rectus*, straight; *linea*, a line).

Uniform rectilinear motion is motion along a straight line with uniform or constant speed.

Velocity is a certain speed in a definite direction, *i.e.* velocity is rate of motion. It is measured when uniform by the amount of motion, expressed in units of length, which takes place in a unit of time. A body moving in a straight line is said to move with *uniform linear velocity* when it passes through equal distances in equal times, *however small these times may be.*

It is important to notice the last words of the definition of uniform linear velocity. A train might move through a mile in one minute and through another mile in the next minute, and yet it might have passed over unequal distances in successive seconds.

When a body does not pass over equal distances in equal times, however small these intervals may be, its velocity is said to be *variable.*

To measure velocity, we require a standard or *unit of velocity.* The unit of velocity in the British system is the velocity of a body which passes over unit length in unit time, *i.e.* a velocity of one foot per second. In the metric or C.G.S.

system, the *unit of velocity* is the velocity of a body that describes *one centimetre in one second.*

In all cases of velocity the unit of distance and the unit of time must both be expressed, unless they are clearly understood. Other units may be employed, as miles per minute, or metres per second, and they can be readily reduced to the standard units if required.

Example.—Express a velocity of 10 miles per hour in British units of velocity, *i.e.* in feet per second.

10 miles per hour may be written $\frac{10 \text{ miles}}{1 \text{ hour}}$. This is equal to $\frac{10 \times 1760 \times 3 \text{ feet}}{60 \times 60 \text{ seconds}}$ =, on cancelling, $\frac{44 \text{ feet}}{3 \text{ secs.}} = 14\frac{2}{3}$ feet per second.

If v represent the number of units of velocity described by a body moving with uniform velocity in a unit of time, then the distance or space described in two units of time will be $v \times 2$, in three units of time $v \times 3$, in t units of time $v \times t$, i.e. vt. Representing the space by s, we see that the space described in one second with the velocity v is v, in two seconds $v \times 2$, in three seconds $v \times 3$, and in t seconds $v \times t$. Hence the algebraic formula—

$$s = vt$$

or the expression—

$$\text{Space} = \text{velocity} \times \text{time}$$

This general equation or formula of calculation for all cases of motion with uniform velocity applies whether we measure in British or metric units, and it is true whatever unit we employ, provided we keep to the same units throughout the particular example.

Example.—A body moves at the rate of 50 feet per second. How far does it move in 5 minutes?

Using the formula $s = vt$, we have $v = 50$ feet per second, and $t =$ 5 mins. = 300 secs. (We must reduce to seconds, as the velocity is given in feet per second.) From $s = vt$ we get here—

$$s = 50 \times 300 = 15{,}000 \text{ feet}$$

Example.—A train travels at a speed of 20 kms. an hour. How far would it go at this speed in 25 mins.?

Taking the kilometres and the hour as units, we have $v = 20$ kms. and $t = \frac{5}{12}$ hour. Hence from $s = vt$ we get—

$$s = 20 \times \tfrac{5}{12} = 8\tfrac{1}{3} \text{ kms.}$$

From the equation $s = vt$ we get, by dividing both sides of the equation by t, the new formula $v = \frac{s}{t}$, *i.e.*—

$$\text{Velocity} = \frac{\text{space}}{\text{time}}$$

This enables us to calculate the velocity when space and time are given. We can also obtain from the equation $s = vt$ by dividing each side by tv, $t = \frac{s}{v}$, that is—

$$\text{Time} = \frac{\text{space}}{\text{velocity}}.$$

This enables us to calculate time when space and velocity are given.

Example.—Find the time required to move through a distance of 1 mile at the uniform velocity of 88 feet per second.

Using $t = \frac{s}{v}$, we get—

$$t = \frac{1 \text{ mile}}{88 \text{ feet}} = \frac{5280 \text{ feet}}{88 \text{ feet}} = 60 \text{ secs.}$$

It will be useful to remember that a velocity of a mile a minute is equal to 88 feet per second. The above examples may also be worked by the rules of simple proportion.

26. A body moving in a straight line may have more than one velocity at the same time. A boat that is being rowed down a stream has a velocity made up of the velocity produced by the rowing and the velocity of the stream. Both velocities are in the same direction, and the velocity of the boat is the sum of the two velocities. Rowed up stream the two velocities are in the opposite direction, and the resultant velocity is the difference of the two velocities in the direction of the greater.

Example.—A stone rolls along a plank due south at the rate of 15 yards a minute, and the plank is being carried due north at the rate of 12 yards a minute. What is the resultant velocity of the stone in foot-second units?

The velocities being in opposite directions, and the greater velocity being south, the resultant velocity is $15 - 12 = 3$ yards a minute due south.

$$\frac{3 \text{ yards}}{1 \text{ min.}} = \frac{9 \text{ feet}}{60 \text{ secs.}} = \frac{3}{20} \text{ feet per second due south}$$

27. **Variable Velocity.**—When a body is moving with variable velocity, *i.e.* when a body moves over unequal spaces in equal times, we may not be able to give its velocity at any instant, yet we can find its *average* or *mean velocity* for any distance traversed, by dividing that distance by the whole time taken to traverse it. A train that runs 180 miles in six hours, though its actual velocity may vary from 0 to 60, runs the distance with an average velocity of $\frac{180}{6} = 30$ miles an hour. It is therefore evident that when a body moves with variable velocity over a given space in a given time, the average velocity is equal to the uniform velocity with which any body would pass over the same space in the same time.

28. **Acceleration.**—Bodies in nature do not move with uniform velocity, but motion with change of velocity is common. The rate of change of velocity is called *acceleration.* "Rate of change" is measured by the amount of change which takes place in a unit of time. Hence *acceleration is the change of velocity per second.* In ordinary language, the word "acceleration" means an increase of velocity, and the word "retardation" is used to denote a decrease of velocity; but in the science of mechanics, *acceleration* is the change of velocity per second, or the rate of change of velocity, whether the change be an increase, a decrease, or a change of direction, for *velocity* is a certain speed in a definite direction. Increase of velocity per second may be called *positive* acceleration, decrease of velocity *negative* acceleration. A body is said to have *uniform acceleration* when it receives equal increments or decrements of velocity in equal times, however small these times may be. For example, if a body is found to have at the end of successive seconds a velocity of 6, 9, 12, 15, and 18 feet per second, it is being uniformly accelerated, for the change of velocity per second is an increase of three feet per second each second, or three feet per second per second. Acceleration, it will be noticed, is measured by the increase of velocity per second. An acceleration of ten means an increase of 10 feet per second each second, and since the element of time comes in twice, we usually express this by saying 10 feet per second per second. As already mentioned, a retardation of velocity

may be regarded as a negative acceleration. A body that starts with a velocity of 100 feet per second, and that has a negative acceleration of 15 feet per second each second, will have a velocity of $100 - (3 \times 15) = 55$ feet per second at the end of three seconds.

29. **The Acceleration produced by Gravity.**—Experiment shows that a heavy body, when allowed to fall freely, falls vertically—

In one second	through	16 feet;		
In two seconds	„	64 feet,	*i.e.* through	16×2^2 feet;
In three „	„	144 „	„	16×3^2 „
In four „	„	256 „	„	16×4^2 „

so that, if we *multiply the square of the number of seconds by* 16, we get the distance in feet through which a falling body descends in a given time from rest.

Now, since gravity is a uniform continuous force acting upon a body, it must act as a uniform accelerating force on a falling body. And since experiment shows a body falls through 16 feet in the first second when it starts from rest, its velocity at the end of the first second must be as much faster than 16 feet as it was slower at the beginning. At the beginning the velocity was zero, so that to pass from rest through 16 feet in one second with the velocity uniformly increasing, the velocity at the end of the first second must be 32 *feet per second.* Gravitation near the earth's surface, being continuous and uniform, will therefore cause a velocity of 32 feet per second during each second that it acts—that is, the *acceleration produced by gravitation is* 32 *feet per second per second.* The number denoting the acceleration due to gravity is often denoted by the letter g.

Remembering the distance fallen through in one second, and the velocity acquired at the end of the first second, a little thought will enable the reader to find the distance traversed in any succeeding second, or the velocity acquired at the end of any number of seconds. Thus at the end of the first second a falling body has a velocity of 32 feet, and if *gravity ceased* to act it would pass through this distance in

the second second. But gravity continues to act, and makes it fall through 16 feet in addition to the 32 feet—through $32 + 16 = 48$ feet in the second second. Add this to the 16 feet fallen through in the first second, we get $48 + 16 = 64$ feet, the distance fallen through in two seconds. In the second second gravity adds another 32 feet of velocity, so that the velocity at the end of the second second is $32 \times 2 = 64$ feet per second.

On throwing a ball or other object vertically upwards, gravity acts as a uniformly retarding force until it comes to rest, when gravity brings it back with uniform acceleration. A little reflection will show that a body thrown upwards takes as long to fall as it does to rise, that the height which it reaches is just equal to the distance it would fall from rest during the time it occupies in rising, and that its initial upward velocity will be the same as its final downward velocity.

30. **Inertia and the First Law of Motion.**—Observation and experiment show that matter has no power of itself to change its own state of rest or of motion; in other words, that force is required to move any piece of matter or to alter its rectilinear motion in any way. This implies that when a body is at rest, a certain resistance must be overcome by the application of an external force before the body can be set in motion, and that if a body is already in motion and we wish to make it move faster or slower or to change the direction of its motion, a force must still be applied, because in each case resistance is to be overcome. The property possessed by all matter of offering resistance to change of state, either of rest or motion, is called *inertia*. This amounts to saying—

Inertia is that property of matter which makes the application of external force necessary before any motion or change of motion can be produced in a body.

A description and account of the property of inertia is contained in the first of the three laws of motion as given by Newton. The first law of motion states: *Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it is compelled to change its state by external forces acting upon it.*

The fact that a body at rest remains at rest when not acted upon by an external force is plainly true and a matter of daily experience. A stone or leaf at rest never begins to move without being acted upon by a force. But the law also states that a moving body would continue to move for ever in a straight line with uniform speed, *provided no external force acts upon the body*. What is the evidence for the truth of this part of the law? We cannot prove it by direct experiment, as every moving body we are acquainted with is subject to the action of several forces—gravity, friction, the resistance of the air, etc. But the nearer we approach to the conditions under which the second part of the law is stated—a body moving and not acted upon by any force—the more nearly does the body continue to move in a straight line with uniform speed. A smooth ivory ball thrown along a rough horizontal grass plane is soon brought to rest by the opposing forces, the friction of the plane and the resistance of the air. Throw it along a large horizontal plane of wood with the same force, and it travels farther, as the friction is then less. Throw it along a smooth sheet of ice, and it remains in motion still longer. Hence we conclude that if we could have a perfectly smooth horizontal surface in a space devoid of air, the ball would move at a uniform speed in a straight line for ever, for a body has no power in itself to alter either its speed or its direction.

Many illustrations of the first law of motion and of the property of inertia are met with in ordinary life. When a person is standing up in a carriage at rest, and the carriage is suddenly moved forwards, the person falls backwards, because, not being fixed to the carriage, his inertia or tendency to keep his state causes him to remain at rest in the position he occupies. This is an example of the tendency of a body to remain at rest when not acted upon by force—"inertia of rest," as it may be called.

As an example of the "inertia of motion," or the tendency of a moving body to continue moving uniformly in a straight line when not acted on by a force, consider first a rider upon a moving object (horse or carriage) that suddenly stops. His *inertia or tendency* to keep his state of motion causes him to

move on so that he falls forward, for the force which stops the carriage is not applied to the rider to the same extent. If a carriage make a sudden turn when moving rapidly, the rider is liable to be thrown on the outer side or the carriage overturned, owing to the tendency of a moving body to continue its motion in a straight line.

31. **Force.**—Newton's first law of motion implies the following definition of *force*:—

Force is any cause which changes or tends to change a body's state of rest or of uniform rectilinear motion.

The definition of force does not tell us what forces are in themselves, but merely what effects are produced by the causes called forces. It must be noticed that a force does not always produce motion, for if counteracted by another force it will only "tend" to change a body's state of rest or motion. Forces that can set bodies in motion, such as attractions, the push or pull of a living agent, or a compressed spring may be called *active* forces; forces that are only able to check or prevent motion, such as friction and all other kinds of resistance, may be called *passive* force.

Forces may be *measured* in various ways. One way of measuring a force is to find the velocity it can impart to unit mass in a unit of time, that is, to find the *acceleration* it can produce. Another mode of measuring a force is to compare it with a unit weight, so that a force is often described as a pressure of so many pounds' weight.

Forces may often be conveniently represented by straight lines, for a straight line of finite length can represent (1) the point of application of a force, (2) its direction, and (3) its magnitude. For example—

(1) The point A represents the point of application of a force F.

FIG. 17.

(2) The direction from A to B represents the line of action and direction of the force.

(3) The length AB represents the magnitude of the force when it contains as many units of length as the force contains *units of force.*

Any unit of length, as an inch or $\frac{1}{4}$ inch, may be chosen in any particular case to represent a unit of force, and then a line of twice that length will represent a force twice as great, and so on.

32. **Newton's Second Law of Motion.**—The second law of motion may be stated thus: *The rate of change of momentum of a body is proportional to the external force producing it, and takes place in the same direction as the force acts.*

A "rate of change" of any quantity is measured by the amount of change that takes place in a unit of time.

Momentum, or Quantity of Motion, denotes the product of the mass of a moving body into the velocity with which it moves. We may take as the unit of momentum a body of 1 lb. which is moving with a uniform velocity of 1 foot in a second. Then the numerical value of the momentum of a body is the product of the number of pounds in it by the number of units of velocity with which it is moving. Experiment shows that when force produces motion in a body, the momentum produced in one second is proportional to the force. Hence force can be measured by the momentum it is capable of producing in a unit of time. A ball of lead weighing 10 lbs. and moving with a velocity of 18 feet a second would strike an obstacle with the same force as a ball weighing 30 lbs. and moving with a velocity of 6 feet a second. The momentum or mass-velocity in both cases equals 180.

In general, momentum = mass $\times$ velocity, and as momenta are exactly proportional to the forces producing them, we can compare forces by comparing the momenta produced by them.

The second law implies that each force acting on a body produces its own change of momentum of the body, independently of any other force or forces that may be acting. This leads us to the consideration of the composition of two forces, or the reduction of two forces to one resultant.

33. **Composition of Forces.**—We often wish to know what effect two or more forces have upon a body, and thus to find out what single force will produce the same result as all the others combined. This single force is called the *resultant*, and the problem of finding it is known as the *Composition of Forces.*

(1) Suppose two forces to act in the *same* direction upon a

point in a body, then they are equivalent to a single force in this direction represented by their *sum*. Thus, if a weight of 6 pounds be hung at the end of a string, and also a weight of 4 lbs., their effect upon a body is the same as if a single weight of 10 lbs. were hung at the end. With more than two forces acting in the *same* direction, their resultant will again be their sum.

(2) Suppose two forces to act in exactly *opposite* directions on a point in a body, then they are equivalent to a single force acting in the direction of the greater, which is represented by their *difference*. Thus if a force of 20 lbs. act in one direction, and a force of 14 lbs. in the opposite direction, the effect is the same as if a force of 6 lbs. acted alone in the direction of the force of 20 lbs.

(3) The method of finding the resultant of two forces acting on a point when the forces are not in the same straight line, but act at an angle to each other, is given by the following rule: *If two forces acting at a point be represented in magnitude and direction by the two adjacent sides of a parallelogram, then their resultant or conjoint effect is represented both in magnitude and direction by that diagonal of the parallelogram which passes through the point.*

This rule is called the *Parallelogram of Forces*. It can be proved by experiment as follows:—

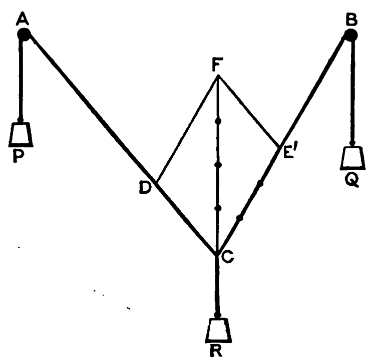


FIG. 18.

Experiment 14.—Fix two smooth horizontal pegs, A and B, on a blackboard or upon a vertical wall. Let three smooth flexible strings be knotted together, C representing the knot. Let one string pass over the peg A, and have a weight, P, attached to its end; let another string pass over the peg B, and have a weight, Q, attached to its end; and let a weight, R, be hung from C. The weights P, Q, and R must be taken so that any two must be greater than the third, as otherwise the weights will not arrange themselves in a position of balance or rest. Suppose, for example, P is a weight of 2 lbs., Q of 3 lbs., and R of 4 lbs. Mark off on the string to

which P is attached, or on the board behind it, two units of length,[1] represent the force P, and also on the string supporting Q three length to represent the latter weight. It will be found, on comple parallelogram CEFD on the blackboard, that the diagonal CF w the same line as the string CR, and will be exactly four units of leng But as R balances P and Q, it must be exactly equal and opposite resultant. Hence CF represents this resultant when CD and CE r P and Q.

34. **Resolution of Forces.**—Just as several forces upon a point may be composed into one resultant, so on may be divided into several others called its "compo which combined together are equivalent to it.

This is done by means of the parallelogram of forces if we represent, as we can do, the original force by a s line, we can regard this line as the diagonal of a paralle whose sides we are trying to find. But round one di any number of parallelograms can be placed, and to det the magnitude of two components we must know the dir they are to have, so as to fix which of these parallelogr the one we must take; or *vice versâ*, to determine the di of the components, we must know their magnitudes.

It is usually convenient, however, to determine th zontal and vertical components of a force; that is to determine them when the angle between the two com forces is a right angle.

Thus, suppose a man is pulling a block of stone alc

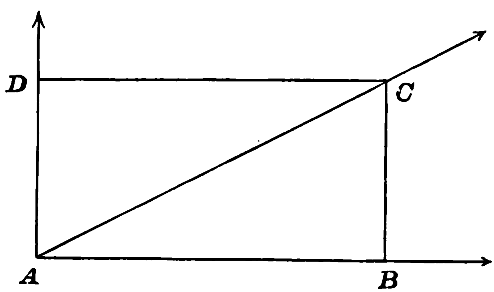


FIG. 19.

ground by means of a rope passing from the stone to hi Now, all the force exerted by the man is not used in di

[1] *Four inches may be conveniently taken as a unit of length*

the stone. If, however, we "resolve" the force into its horizontal and vertical components by means of the parallelogram of forces, we can find, by comparing on the same scale the length of the line representing the original force with those representing the components, what portion of the force exerted by the man is used in dragging the stone along, and what portion tends to lift the stone.

Suppose the force exerted by the man is equal to a weight of 50 lbs., acting at an angle of 30° to the horizontal. Letting 1 inch represent 25 lbs., draw a line, AC, 2 inches long, making an angle of 30° with the horizontal. Then draw the parallelogram, having AC as diagonal, with its adjacent sides at right angles. This will give the vertical and horizontal components of the force, the former, AD in this case, being represented by a line 1 inch long, and the latter, AB, by a line 1·7 inch long. Hence we learn that a force of 25 × 1·7, *i.e.* 42·5 lbs., is being spent in moving the stone in a horizontal direction, whilst one of 25 lbs. tends to lift the stone upwards. By inclining the rope at various angles to the ground, and determining the components in each case on completing the parallelogram, the student can find out for himself what effect the inclination of the rope to the horizontal has upon the relative magnitudes of the components, and thus prove why less force is required to drag the stone the more the direction of the applied force is in the same straight line as the direction in which we wish to move the stone.

35. **Newton's Third Law of Motion.**—The third law of motion states, *To every action there is an equal and opposite reaction.* It means that every exertion of force consists of a mutual action between two bodies; that whenever a change of momentum is produced in a body by a pressure or pull exerted by some other body, just the same change of momentum is produced in that other body in the opposite direction. Action and reaction together form the *stress* between the two bodies, i.e. *stress is the pair of equal and opposite forces constituting the mutual action between two bodies.* We often think of only one of the masses between which a stress is acting, and of only one part of the stress, and thus speak of the force

acting upon a body, thus neglecting for the time the reacting force.

Strain is the alteration in the shape or size of a body produced during the action of a stress. A beam is said to undergo a strain if compressed, or stretched, or bent, or distorted in any way. Illustrations of the third law of motion are found in the recoil of a gun, in the ascent of a rocket, and in the mutual attraction of a magnet and a piece of steel.

36. **Conversion of Retilinear into Circular Motion.**— When a body is moving in a straight line, the motion is termed *rectilinear;* when a body moves in a curve, the motion is termed *curvilinear*, or if the curve be equidistant from a fixed point, *circular*.

Newton's first law of motion (par. 8) shows that when a body is once put in motion, it will continue to move in a straight line with uniform speed unless acted upon by some force. Hence in every case of curvilinear motion, there must be a force deflecting the moving body from a rectilinear path. If a body is moving *uniformly* in any other path than a straight line, some force must be continuously deviating it from a straight line. Consider the case of a stone swung round in a circle at the end of a string. If the string should break, the stone will move off in a straight line along a tangent to the circle at whatever point in the circle the stone then happened to be. The force that converts this rectilinear motion into a circular motion, or the force which compels the stone to describe a circle, is called *centripetal force* (Lat. *peto*, I seek), because it is a force seeking or acting towards the centre of the circle. *This force is constant* in magnitude, and being always at right

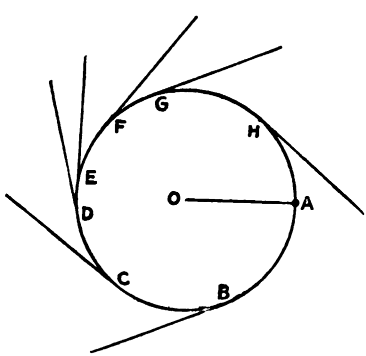


FIG. 20.—Showing how a stone whirled in a circle would fly off at a tangent if suddenly released.

angles to the direction of the moving body, neither accelerates nor retards its velocity round the circle.

The rectilinear motion of a body may therefore be converted into circular motion by a force acting continuously upon the body at right angles to its natural rectilinear path. For uniform circular motion, the value of this centripetal force is represented by the formula $f=\frac{mv^2}{r}$, where m is the mass or weight of the body, v the velocity, and r the radius, *i.e.* the force varies directly as the mass of the body multiplied by the square of the velocity, and inversely as the radius of its circular path. This shows that when a stone is whirled round by a string, the larger the stone, or the quicker it whirls, the greater the centripetal force. The force exerted by the hand drawing the stone towards the centre, and causing the tension in the string, is this centripetal force. There is, of course, the reaction of the stone upon the string, which is equal and opposite, and this is sometimes spoken of as *centrifugal force* (Lat. *fugio*, I flee). The tendency of the stone, however, is not to move *outwards* from the centre, but in a straight line tangential to the circle, in consequence of its inertia, and it is only turned from its natural straight path by the central force pulling it into a circular path.

What is termed "centrifugal force" is in fact not a force at all, but only an instance of the effect of inertia, the inertia of rotation.

Examples of this tendency to fly off at a tangent are seen in the drops of water flung off in the direction of tangents to the circular outline of a wet mop that is being quickly twirled, in the flying outwards of the governor balls of a stationary engine as the velocity increases, and in many experiments with a whirling-table.

Experiment 15.—Attach equal short threads to the outer edge of a circular card with a hole in the centre, and to the free ends of each thread fasten a light pith ball. Slip the card over the upper part of a rapidly spinning top, and observe how the balls spread out in a horizontal circle owing to the tendency to move off at a tangent.

Experiment 16.—Fix to the vertical axis of a whirling-table an iron rod at the bottom of which are fastened four elastic hoops of metal, the hoop being joined at the top to a ring capable of sliding up and down the rod. On rotating the apparatus the ring slides down the rod, and the hoops bulge

out at the centre owing to the tendency to fly outwards from the centre of rotation. At a great speed the impression of the separate strips run together, and give to the eye the appearance of an oblate spheroid.

FIG. 21. — Explanation of the spheroidal form of the earth.

Examples of centripetal force may be found in astronomy. The moon's motion is due to a combination of two velocities, revolving round the earth in an orbit nearly circular because deflected from a natural rectilinear path by a centripetal force, viz. the earth's gravitative attraction. In fact, Newton showed that its path may be regarded as compounded of an original impulse in a rectilinear direction, and a constant pull—the force of gravitation—towards the earth's centre, and that generally, were a planet projected with a certain velocity in a direction right angles to the radius connecting the planet and the sun, the planet would for ever describe a circle round the sun.

It is easy to understand that some modification of this velocity or direction of projection may lead to other closed curves than a circle, *e.g.* an ellipse, and the law of gravitation, according to which the force of attraction varies inversely as the square of the distance, combined with a certain specific initial impulse, has been proved to explain the elliptical paths of the planets, and their varying velocity in different parts of the orbit.

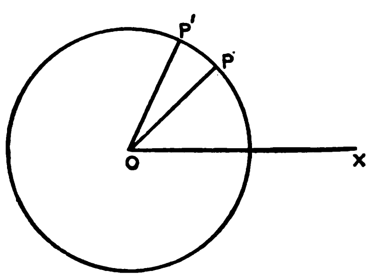


FIG. 22.

37. **Angular Velocity.** —When a body is rotating about a fixed axis or fixed point, each particle describes a circumference whose centre is the axis. Suppose the point O to be an axis, and P a point on a fixed line Ox; then the rate at which the angle POx increases is

called the ***angular velocity*** of P about the point O. Angular velocity is therefore the angle passed through by a rotating point in a unit of time. It is evident that every point on the line OP, when OP represents the rotating body, will describe the same angle in the same time, but that the *linear* velocities of the particles will increase as the distances of the particles from the fixed point O increase.

The unit of angular velocity is that which the point has when it describes unit angle in one second. The unit angle used in angular velocity is called a ***radian*** (the radian = $57{\cdot}3^{\circ}$), that is, the unit of angular velocity is *one radian per second.* Angular velocity may also be expressed in degrees per second.

CHAPTER V.

PARALLEL FORCES AND MACHINES.

38. FORCES whose line of action are parallel are called *parallel forces*. If the parallel forces act in the *same* direction, they are known as *like parallel forces*; if they act in *opposite* directions, they are said to be *unlike parallel forces*.

We will first of all show that for two like parallel forces—

(1) The resultant acts in the same direction as the forces.

(2) It is equal to their sum.

Experiment 17.—Take a light uniform bar of wood (about a metre long) and suspend it to the hook of a spring balance by a string passing through a hole at the centre of the rod, so that the latter can turn quite freely about

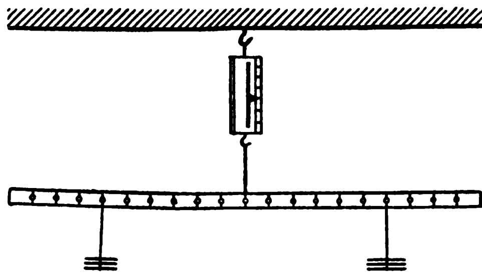


FIG. 23.

its point of suspension. Mark on the bar equal divisions from the centre, and at each division bore a small hole. Make several hooks of bent wire, and when necessary insert a hook into the hole from which you wish to suspend a weight. The rod will now swing freely and rest in any position, its weight being indicated by the spring balance. Attach in any way some small weights to one of the hooks, *e.g.* one of 3 units (pounds, ounces, or grams, or any other convenient unit) on the hook distant six divisions from the centre. That side of the rod will be drawn down, but on putting an equal weight at an equal distance on the other side, the counterpoise will be restored and the rod brought back to its original position. Notice the

pull indicated on the spring balance. Remove the two sets of weights, and suspend them both from the centre division. The spring balance shows that the pressure of the bar upon its support is exactly the same as in the former case. We therefore see that two forces of three units each acting in parallel directions—in this case vertically downwards—on a bar have a combined effect of six units acting in the same direction. Vary the experiment by attaching two or three sets of different weights to the hooks at different distances on each side of the centre so that the bar may keep horizontal. Note the pull on the spring balance, and then hang them all on to the centre hook. Again it will be found that their combined effect is the same as before.

Therefore the *resultant of a number of like parallel forces is numerically equal to their sum, and acts in the same direction as the forces themselves.*

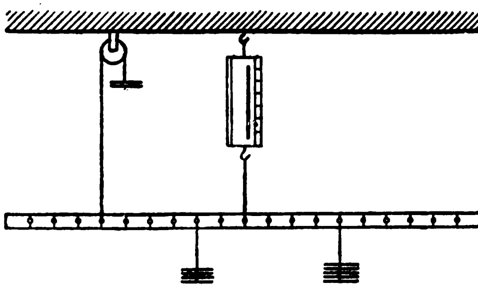


FIG. 24.

Let us now consider the case of unlike parallel forces, and endeavour to prove that—

(1) The resultant acts in the same direction as the *greater* of the two sets of forces.

(2) It is equal to their difference.

Experiment 18.—Fit up the apparatus as in the preceding experiment, but turn one of the hooks upside down. Attach a weight to this hook by a string passing over the pulley. The effect of the pulley, as we shall afterwards show, is merely to allow the weight to act upwards upon the rod, and does not alter its magnitude. Let a force of 2 units, for example, act in an upward direction on the sixth hook from the centre, and hang on to the other hooks any suitable weights so as to keep the bar horizontal, as shown in the figure. Subtract from the sum of the weights acting downwards, the weight whose force is directed upwards, and it will be found that their difference is their combined effect on the rod, as indicated by the balance, after the weight of the rod has been allowed for.

This proves that, as stated above, *the resultant of unlike*

parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction.

39. **Machines.**—A machine is an instrument by means of which a force can be applied at one point so as to overcome a weight or resistance at another point. This is done either (1) by means of a solid body which is movable about a given point, or (2) by means of a flexible band or string, or (3) by means of a hard inclined surface.

The simple machines, therefore, are (1) the lever, (2) the pulley, and (3) the inclined plane.

A machine may be considered to be acted upon by two forces—

(1) An external force applied to work the machine; this is called the *power*.

(2) A resistance to be overcome; this is called the *weight*.

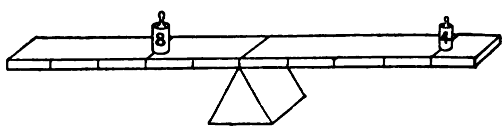


FIG. 25.

It is usually the object of a machine that a small power shall overcome a large resistance or weight.

40. **The Lever.**—A lever is a rigid bar capable of turning about a fixed point called the *fulcrum*. The fulcrum may be an axle passing through the lever, or an edge upon which it rests. The portions of the lever measured from the fulcrum to the power and weight respectively are called the arms of the lever.

Experiment 19.—Make a lever by balancing a stiff lath upon the edge of a triangular prism, cutting a small grove on the under surface of the lath to enable it to rest more firmly on the edge of the prism. (A lever may also be made with a lath or ruler by boring a hole through its centre so that the rod will remain horizontal when suspended on a nail passing through the hole.)

Place or suspend a four-ounce weight, for example, on one side of the lever, and then restore the balance by placing or suspending an equal weight on the other side. It will be found that the two weights are at *equal distances* from the fulcrum, *i.e.* that the two arms of a lever are equal

when the power equals the weight. Now take an eight-ounce weight and place it at a short distance on one side of the fulcrum, and find the position on the other side at which the four-ounce weight will balance it. The distance of the four-ounce weight from the fulcrum will be found to be double the distance of the eight-ounce weight from the fulcrum. With a twelve-ounce weight, the distance of the four-ounce weight will be three times that of the larger weight. We thus prove that when the lever is in equilibrium—

$$\left.\begin{array}{l}\text{Balancing force} \times \text{its perpendicular} \\ \quad\text{distance from fulcrum}\end{array}\right\} = \left\{\begin{array}{l}\text{weight} \times \text{its perpendicular dis-} \\ \quad\text{tance from fulcrum}\end{array}\right.$$

This may also be expressed thus: *The product of the power and its arm is equal to the product of the weight and its arm.*

Experiment 20.—Pivot a lever upon a nail as shown in the figure, so that PC is twice WC. Place a weight of 1 lb. at P, and balance it with a force or pull of 2 lbs. at W. Disturb the lever from its horizontal position of rest, and find the lengths of the small arcs described by the ends of each arm. The area P*p* will be found to be twice the length of the arc W*w*. Try the experiment with one arm thrice the length of the other. It will be found that the lengths of the two arcs are always in the same proportions to each other as the lengths of the arms. We thus see that—

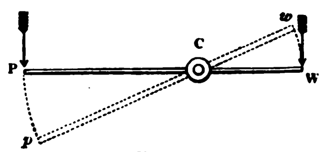


FIG. 26.

$$\text{Power} \times \text{space it passes through} = \text{weight} \times \text{space it passes through}$$

Now, *work* is measured by the product of the force into the distance through which the resistance is moved in the direction of the force. Hence we see that in the lever, as in every other machine—

Work expended = work obtained

We now see clearly why it is possible to move great weights, or overcome other great resistances, by a lever when we exert a small force through a great distance in order to move the weight through a small distance. But "what is gained in power is lost in speed," since the small force must move through its great distance *in the same time* that the weight is moved through its small distance.

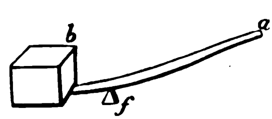


FIG. 27.

Example.—A block of stone weighing 2¼ cwt. is to be raised 3 inches by a crowbar 3½ feet long. Suppose a fulcrum placed as in the figure, 7 inches from one end of the lever. *Find the force required at the other end to raise the stone, and the distance through which the force must move.*

By the principle of the lever—

$$\text{Power} \times af = \text{weight} \times bf$$
$$i.e.\ P \times (42 - 7) = 280 \text{ lbs.} \times 7$$
$$i.e.\ P = \frac{280 \times 7}{35} = 56 \text{ lbs.}$$

Again, power × distance moved through = weight × distance moved;

$$i.e.\ 56 \times D = 280 \times 3$$
$$i.e.\ D = \frac{280 \times 3}{56} = 15 \text{ inches}$$

41. **The Three Classes of Levers.**—Levers are usually divided into three classes :

(1) The *fulcrum* (F) between the force (power) and the weight (resistance).

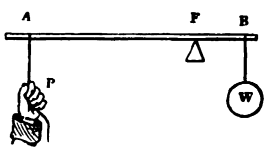


Fig. 28.—Lever of first order (fulcrum in the middle).

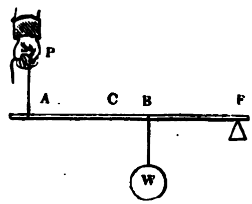


Fig. 29.—Lever of second order (weight in the middle).

(2) The *weight* (W) between the power and the fulcrum.

(3) The *power* (P) between the weight and the fulcrum.

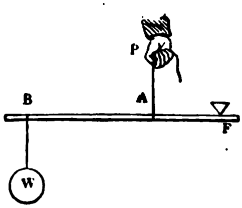


Fig. 30.—Lever of third order (power in the middle).

(The order of the letters F, W, P gives the middle position in order of the three classes.)

In all cases the rule already given holds good : The product of the power into its arm is equal to the product of the weight into its arm. This rule may be called *the principle of the lever.*

As examples of the *first* class may be mentioned a common balance, which is a lever with equal arms (Fig. 31), a poker resting on the bar to uplift the coals, a crowbar moving a resistance at its end and resting on a fulcrum near the end (Fig. 27), a pump-handle. A pair of pincers is a double lever of the first class. In gripping a nail or other object with them, the

common hinge is the fulcrum. In drawing a nail, the instrument is often made to rest on one shoulder as a fulcrum. A pair of scissors is also a double lever of the first class, the fulcrum being the rivet at the hinge, and the object to be cut being the weight or resistance.

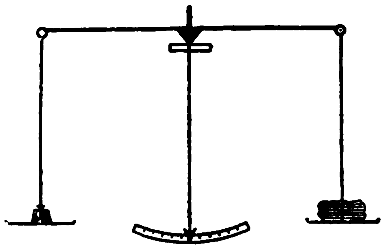


FIG. 31.—Balance with equal arms.

As examples of the *second* class may be mentioned a cork-squeezer (Fig. 32), a crowbar with the point on the ground, a wheel-barrow (Fig. 33), and the oar of a boat. In this last case, the power is applied at the

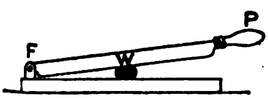


FIG. 32.

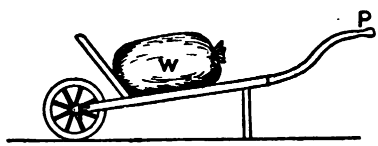


FIG. 33.

handle, the weight is the boat moved by the pressure at the rowlock, and the fulcrum is the water against the blade

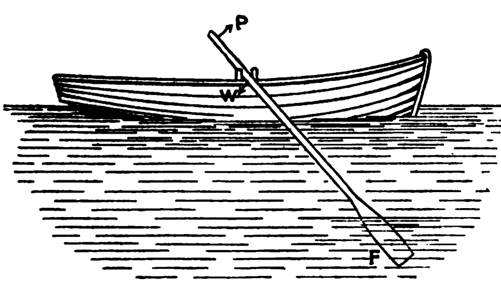


FIG. 34.

(Fig. 34). A door moved on its hinges is also a lever of the second class. The power is applied at the handle, the resistance

is the mass of the door itself acting at its centre of gravity, the fulcrum is the hinges. A pair of nut-crackers may be regarded as a combination of two levers of the second class. The common fulcrum is the pin or pivot at one end, the resistance is the nut to be cracked, and the power is the force of the hand exerted at the other end.

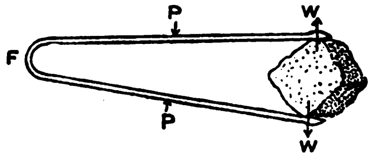


Fig. 35.

As examples of the *third* class of levers, where the power is exerted between the fulcrum and the resistance, may be mentioned a pair of tongs (Fig. 35), and a pair of shears. Another interesting example is the fore-arm used in lifting a weight. Here the fulcrum is the elbow-joint, the resistance is the weight in the hand, and the power is the force applied by a muscle attached to a bone of the fore-arm (Fig. 36).

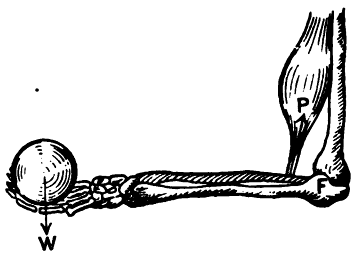


Fig. 36.

42. Mechanical Advantage.—The mechanical advantage of a machine is the ratio of the weight to the power, *i.e.* the fraction $\frac{\text{weight}}{\text{power}}$.

It may also be obtained by dividing the space moved through by the power by that moved through by the weight or resistance, *e.g.* in using a crowbar, if the end where the power is applied is moved through 2 feet whilst the other end, placed under a block of stone, moves through 3 inches, the mechanical advantage $= \frac{2 \text{ feet}}{3 \text{ inches}} = \frac{24}{3} = 8$, *i.e.* a pressure of 20 lbs. would lift a block of stone 20×8, *i.e.* 160 lbs. in weight, though exactly the same amount of work (40 foot-pounds, par. 40) has been done at each end of the bar.

In calculating the mechanical advantage of a lever, we may consider the lengths of the arms instead of the distances moved

through by the power and resistance, for it is obvious that the latter are dependent on the former. Thus, if the power arm is twice as long as the resistance arm, the power will move through twice the space as the resistance when the lever is in use. In the case of a lever, therefore, we may say that—

$$\text{The mechanical advantage} = \frac{\text{length of the power arm}}{\text{length of the resistance arm}}$$

Example.—In a lever of the first order, which is used to raise a stone (Fig. 27), the distance of the power from the fulcrum is 5 feet, and that of the resistance is 1 foot. What power would be required to move a weight of 40 lbs.?

Here mechanical advantage $= \frac{5 \text{ feet}}{1 \text{ foot}} = 5$, *i.e.* a power of 1 lb. would move a weight of 5 lbs.; therefore to move a weight of 40 lbs. a power of $\frac{40}{5}$, *i.e.* 8 lbs., would be required.

In a lever of the first kind there may or may not be a mechanical advantage according as the power-arm is longer, equal to, or shorter than the resistance arm; in a lever of the second kind there must be a mechanical advantage, since the power is always further from the fulcrum than the resistance; whilst in a lever of the third kind we get a *mechanical disadvantage*, since the resistance is at the end, and therefore moves through a greater space than the power. Hence in the third kind the power will always have to be greater than the resistance; and therefore this kind of lever is only used for convenience' sake where the resistance to be overcome is small.

43. **The Pulley.**—A pulley consists of a circular disc of wood or metal called the *sheaf*, having a grooved circumference or edge, which can turn freely about an *axle* passing through its centre. The axle is supported by a framework called the *block*. In the groove a cord is placed, to one end of which the power is applied, whilst the other end is attached to the resistance to be overcome. Pulleys are of two kinds—*fixed pulleys* and *movable pulleys*. A fixed pulley is one which is attached to some support, such as a beam, so that the pulley as a whole does not alter its position. On the other hand, a movable pulley, as its name implies, is one which itself moves as the power is applied. It is supported by the cord, and

supports the resistance. Let us first consider the case of a single fixed pulley.

Experiment 21.—Fit up a single fixed pulley as shown in the figure. It will be noticed that the power as indicated by the spring-balance is exactly equal to W, the weight, when there is equilibrium. Since the power moves through the same distance as the weight, as is seen by raising the weight, it follows from this, also, that a single fixed pulley gives no mechanical advantage. In raising heavy weights it is often much more convenient to apply the force downwards, and it is for this reason that fixed pulleys are often used. The tension or pull on a cord is therefore unaltered in magnitude, but merely changed in direction, by using a fixed pulley.

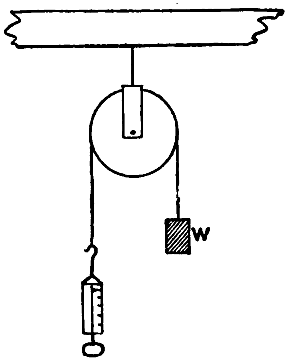


FIG. 37.—A single fixed pulley.

Now perform the following experiment to illustrate the use of a single movable pulley :—

Experiment 22.—Fit up a single movable pulley as shown in the figure, either without or in connection with a single fixed pulley. In both cases it will be found that the power required to hold the weight is one-half that of the weight itself. Since both parts of the string on each side of the pulley bear an equal share of the weight, it follows that the tension or pull in one part is only one-half that of the weight, as is shown by the spring-balance. That this is so is also evident from the fact that in this case the power moves through twice the distance that the weight does, and therefore the mechanical advantage $\left(\frac{\text{weight}}{\text{power}}\right)$ is 2, *i.e.* $P = \frac{1}{2}W$. It should be noticed that in this case we neglect the weight of the pulley. If the pulley itself is heavy, it increases the resistance to be overcome, in which case the power required will be one-half the *total* resistance or weight.

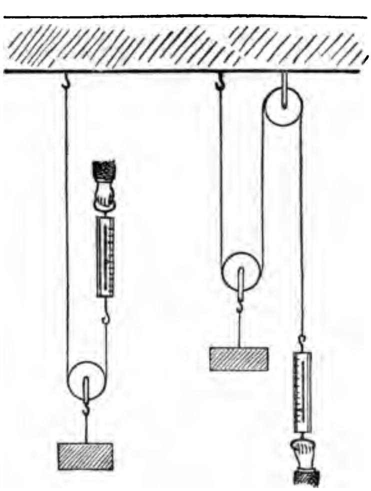


FIG. 38.—A single movable pulley.

Two movable pulleys would give a mechanical advantage of 4, and so on.

Example.—In a single smooth movable pulley, if the weight of the pulley be 1 lb., find the force required to raise a weight of 7 lbs.

Here the total weight is 7 + 1, *i.e.* 8 lbs.

Hence the force required to *support* the weight would be $\frac{8}{2}$, *i.e.* 4 lbs., because in this case the power is half the weight. If the power, then, be a little more than this, the weight will be raised.

Answer. Just over 4 lbs.

When the weight of the pulley is not mentioned, it need not be taken into account.

44. **The Inclined Plane.**—An inclined plane in mechanics is a smooth hard plane fixed in a position inclined to the horizontal. It can be represented by a right-angled triangle, ABC. The horizontal side BC is called the *base*, the vertical side AC is called the *height*, and the hypotenuse AB is called the *length*. The angle ABC is the inclination of the inclined plane to the horizon. Let us consider the forces in action when a smooth heavy body, O, is supported on the incline AB. Now, O is in equilibrium under the action of three forces: (1) the weight of the body acting vertically downwards through its centre of gravity; (2) the force P acting along OP parallel to the length of the plane; (3) the resistance of the plane OQ, which acts at right angles to its length. We can find the proportion of these three forces to each other by experiment[1] or by reasoning. The proportion of the power to the weight is the most important of these relations, and experiment proves: *When a weight is kept at rest on an inclined plane by a power acting parallel to the plane, the power is to the weight in the same proportion as the height of the plane is to its length.*

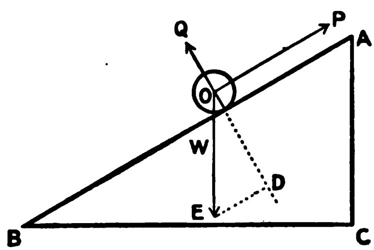


FIG. 39.—Section of roller on inclined plane.

This may be expressed thus:

$$\frac{\text{Power}}{\text{weight}} = \frac{\text{height of plane}}{\text{length of plane}}$$

[1] The experiment may be performed by attaching a spring-balance to smooth cylinders of various weights on an inclined plane which can be set at different inclinations to the horizontal.

Example.—Suppose the power to act parallel to the plane, and that the height of the plane is 15 inches, and that its length is 1 yard, what power would be required to support a weight of 65 lbs.?

Substituting the given values in the above equation, we get—

$$\frac{P}{65} = \frac{15}{36}$$

$$\therefore P = \frac{65 \times 15}{36} = 27\tfrac{1}{12} \text{ lbs.}$$

Returning to the three forces in equilibrium when the body O is at rest on the inclined plane, we will show how their relations to each other may be established by reasoning. By producing QO and drawing ED parallel to P, we obtain a triangle, EOD, whose sides are parallel to the directions of the three forces. Now, we know that if three forces acting on a body keep it in equilibrium, and a triangle be drawn having its sides parallel to the lines of action of the forces, the sides of this triangle will be proportional to the forces. Hence (Fig. 39) the power is to the weight in the same proportion as ED is to EO. But by measurement or by Euclid it can be shown that the triangles ABC and EOD are *similar*, and that therefore the corresponding sides are proportional, *i.e.* $\frac{ED}{EO} = \frac{AC}{AB}$. Now, $\frac{P}{W} = \frac{ED}{EO}$, and therefore the force P is to weight W as side AC is to side AB, *i.e.* $\frac{P}{W} = \frac{AC}{AB}$, or $P = \frac{W \times AC}{BA}$.

The same fact is expressed by saying that the mechanical advantage of an inclined plane is represented by the ratio—

$$\frac{\text{length of plane}}{\text{height of plane}}$$

which is equal to—

$$\frac{\text{distance moved through by power}}{\text{distance moved through by resistance}}$$

A road up a hill is the commonest example of an inclined plane, and the gradient or slope of the road is often expressed thus: 1 in 50, *i.e.* in every 50 feet of length the road rises 1 foot in height, or, in other words, if the plane were 50 feet long, its height is 1 foot, and therefore the mechanical advantage is $\frac{50}{1}$, *i.e.* 50, whatever the actual length of the road might be.

Example.—Find the force required to roll a cask weighing $7\frac{1}{2}$ cwt. up a plank 12 feet long into a waggon 3 feet high.

From the equation showing the relation of the power to the weight, we get—

$$\frac{P}{7\frac{1}{2}} = \frac{3}{12}$$

$$\therefore P = \frac{3 \times 7\frac{1}{2}}{12} = 1\tfrac{7}{8} \text{ cwt.}$$

$$= 210 \text{ lbs.}$$

45. **The Screw.**—This machine consists of a circular cylinder or roller with a uniform projecting ridge or thread running spirally round the surface, the thread always making the same angle with lines drawn parallel to the axis of the cylinder. The screw thus formed fits in a block through which is bored a hollow cylinder (Fig. 40), into which the thread of the screw works. This block is called the companion screw or nut. The student may form a good idea of the construction of a screw by considering it made as follows:—

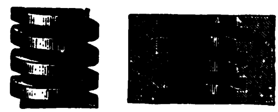


FIG. 40.—Screw and nut.

Let there be a rectangular piece of paper whose base is A*a* and sides AD, *ad*. The base A*a* is to be equal to the circum-

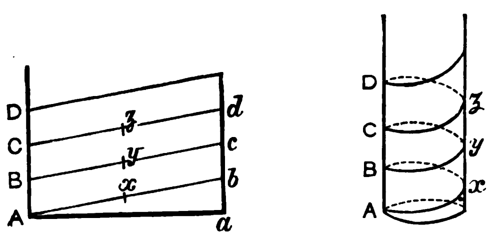


FIG. 41. (*From Geldard's Dynamics.*)

ference of the cylinder round which the paper will be wrapped. Cut off equal parts AB, BC, CD, *ab*, *bc*, *cd*, etc. Join A*b*, B*c*, C*d*, etc., and bisect the lines at *x*, *y*, *z*, etc. (Fig. 41). Fold the rectangular piece of paper round the circumference of the cylinder; then *b* coincides with B, *c* with C, *d* with D, etc.; and the points *x*, *y*, *z*, etc., are on the opposite sides of the cylinder (Fig. 41). The lines A*b*, B*c*, C*d* will form a continuous spiral line round the cylinder. If this spiral line projects, it will be the thread of the screw. This thread will clearly be

inclined at the same angle to all lines on the surface of the cylinder which are parallel to its axis.

The pitch of a screw is the distance between one surface of a thread and the similar surface of the next consecutive thread, the distance being measured parallel to the axis. In Fig. 41 the height *ab* gives us the pitch of the screw. One turn of the screw will make it advance a distance equal to its pitch.

In using a screw, the power causes it to revolve in its nut and to overcome the resistance or weight acting at the end of the screw. The relation of the power to the weight may be thus expressed:

$$\frac{P}{W} = \frac{\text{pitch}}{\text{circumference of screw}}$$

In practice, however, the power is usually applied horizontally

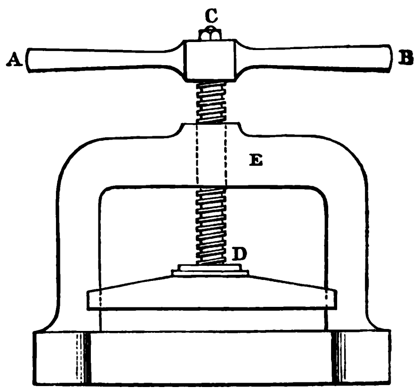


FIG. 42.—A screw-press. (*From Magnus' Lessons in Elementary Mechanics.*)

at the end of a handle or lever fixed to the screw, and the power then moves through a distance equal to that of the circumference of the circle through which the handle moves. The relation of the power to the resistance is then expressed thus:

$$\frac{P}{W} = \frac{\text{pitch of screw}}{\text{circumference of circle through which end of handle moves}}$$

Example.—What power will be required to sustain a weight of 1 cwt.

upon a screw whose pitch is $\frac{1}{4}$ inch, and whose lever arm is 21 inches from the centre of the screw-cylinder?

Here we first find the circumference of the circle through which the handle moves. Since the circumference of a circle is $3\frac{1}{7}$ times the diameter, and the diameter is twice the radius or lever arm, the circumference required is $21 \times 2 \times 3\frac{1}{7} = 132$ inches. Hence we get—

$$\frac{P}{W} = \frac{\frac{1}{4}}{132}$$

$$\therefore P = \frac{\frac{1}{4} \times 112}{132} = \frac{7}{33} \text{ lb.}$$

By making the pitch of the screw very fine, and using a long arm to apply the power, an enormous mechanical advantage is obtained, though in use a great deal of the power is spent in overcoming *friction.*

There are many useful applications of the screw, *e.g.* the screw-jack used for lifting great weights, and the common screws used for fastening parts of wood together. In the common screw the threads are thin and sharp, and make grooves for themselves as they penetrate the wood. A screw is also often used, not to support a weight, but to exert a pressure. Fig. 42 illustrates what is known as a screw-press, where AC and BC are two lever arms, CD the cylinder of the screw, and E the nut.

CHAPTER VI.

CENTRE OF GRAVITY.

46. **Centre of Gravity.**—We may consider any body to be made up of an immense number of small particles, and we know that the attraction of the earth on each particle acts in a straight line perpendicular to the horizontal plane. These forces act towards the earth's centre, and may therefore, for all practical purposes, be considered to be *like parallel forces.* The resultant of all these forces is equal to their sum, and acts in the same direction at some definite point of the body (par. 38). This resultant is called the weight of the body.

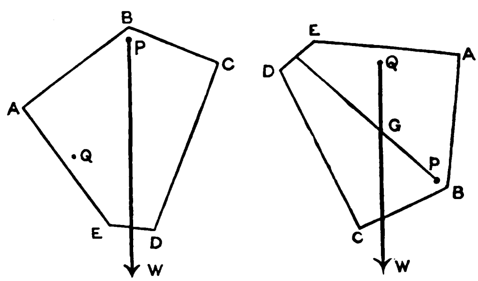


FIG. 43.

We may thus consider the whole weight of the body to be collected at a certain point; and every mass, whatever be its shape, has such a point, to which the name of *centre of gravity*, or *centre of mass*, is given. *The centre of gravity of a body is*, therefore, *that point of it at which the whole weight of the body may always be supposed to act.*

A practical way of finding the centre of gravity of a body ed in the following experiment:—

Experiment 23.—Take an irregular sheet of metal, cardboard, wood, or slate, and bore two holes through it anywhere, as at P and Q (Fig. 43). Suspend the plate by hanging it up on a nail through one of the holes (or by passing a string through the hole and fastening the string to the nail). By means of a plummet (Fig. 3), mark on the plate the vertical direction from the hole P. Again suspend the plate, but this time from the hole Q, and again mark the vertical as before, after allowing the plate to come to rest. Each time the body is at rest or in equilibrium under the action of two forces, viz. its weight acting vertically downwards and the resistance of the nail. These two forces must therefore be equal and opposite, and consequently the centre of gravity must lie somewhere in the vertical PW drawn from the point of support. By a similar reasoning, in the second case the centre of gravity must also lie in the vertical QW, and therefore must be at the point of intersection G of the lines PW and GW. Now hang the plate up by a third corner, and show that the vertical again passes through the centre of gravity.

It should be noticed that the definition of the centre of gravity does not say that it is a point *in* a body, because it often lies outside the substance of the body.

Experiment 24.—Take a flat ring or hoop and suspend it from two different points, marking the vertical from each point of suspension by means of two thin threads tied across the ring. The point of intersection of the threads is the centre of gravity of the ring, and this point is not inside the substance of the ring at all. As a body will balance if it be supported at its centre of gravity, it will be found that the ring may be balanced at the point of intersection of the threads.

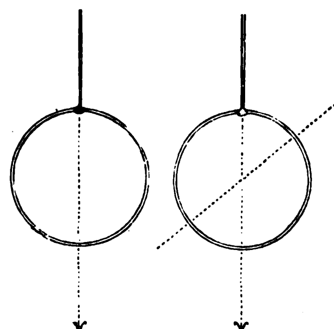


FIG. 44.

This method of finding the centre of gravity can be applied to any body consisting of a framework, as a bent wire, a skeleton cube, or a chair. It is not, however, applicable to many solid bodies, as we are unable to get inside to draw the verticals.

47. Centre of Gravity of Symmetrical Bodies of Uniform Density.—Every symmetrical body is composed of geometrical parts similarly related to one another, and the centre of gravity of such bodies is always the geometric centre; thus the centre of gravity of a uniform straight rod is at its middle point, that *of a sphere at its centre,* that of a square or rectangle at the

intersection of its diagonals, that of a cylinder at the middle point of its axis, that of a circular plate of uniform thickness at its centre, and so on.

48. **Conditions of a Body remaining at rest on a Surface.**—Since the centre of gravity is the point where the whole action of gravity on a body is concentrated so that its weight acts vertically downward from this point, it follows that whenever the vertical from the centre of gravity falls within the base of support, the action of gravity on the body will be counterbalanced, and the body will remain at rest. If the vertical from the centre of gravity falls without the base of support, gravity is not counterbalanced, and the body will overturn (see Figs. 45, 46, where G indicates the centre of gravity, and GW the vertical direction in which the weight acts). Such a structure as the leaning tower of Pisa remains standing because the vertical from its centre of gravity still falls within the base of support. By the base of support is meant the area enclosed by a string drawn round the points where the body touches the supporting surface. In balancing a stick resting by one end on a finger, the base of support is very small, and the difficulty is to keep the centre of gravity of the stick vertically over this base. The smaller the base of support the less the displacement that causes the vertical to fall outside it, and *vice versâ.*

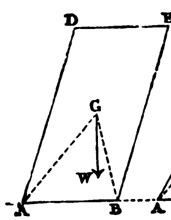


FIG. 45.

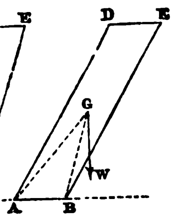


FIG. 46.

When a man stands on both feet, his base of support is the area included within a string passing round his feet. His centre of gravity, situated near the middle of the lower part of his trunk, falls within this base when standing upright. With a sack of flour upon his back, he must lean forward to bring the new centre of gravity of himself and the flour over the base of support; with a bucket of water in his right hand, he leans his head and body to the left for the same reason.

Again, if the centre of gravity of a body is relatively ***high***, ***it is in greater*** danger of being overturned than when it is low,

for a slight displacement will then bring the centre of gravity to a position in which the vertical from it falls outside the base of support. The heaviest parts of an object should be kept lowest to ensure the most stable equilibrium.

A cone resting on its base returns to its position if but slightly disturbed, for a slight disturbance raises its centre of gravity, and the centre of gravity always seeks the lowest position owing to the fact that its weight acts vertically downwards. A *suspended* body always takes up a position so that its centre of gravity is vertically beneath the point of support, and if it be moved from this position, its centre of gravity will be raised, and it will fall back again if free to do so.

A cone balanced on its apex has its centre of gravity in the highest position possible and but a small base of support,

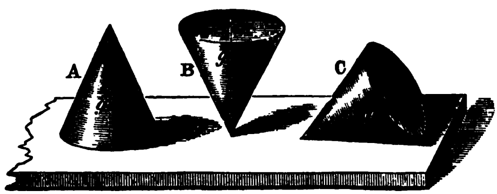


FIG. 47.

so that it falls with the slightest disturbance. The positions of the cone in Fig. 47 illustrate three conditions or states of equilibrium.

In the first case, where the centre of gravity is in the *lowest* position possible, the body is said to be in *stable equilibrium*; in the second case, where the centre of gravity is in the *highest* position possible, the body is said to be in *unstable equilibrium*. A body like a sphere or a cone resting upon its side, which remains at rest equally in any position, is said to be in *neutral equilibrium*.

In the case of *two* bodies, we could ascertain their centre of gravity if we connected them with a rigid straight bar, and then found the point in the bar where they would balance. With two equal globes this point would be midway between the *two*. *If* one were heavier than another, the centre of

gravity would be nearer the heavier in the ratio of its grea weight, and were one much heavier than the other, the cer of gravity would be within the larger. This is the case of sun and the earth, the sun's mass being so much greater t the common centre of gravity of the sun and earth is very n the sun's centre.

CHAPTER VII.

WORK AND ENERGY.

49. **Work.**—Newton's first law of motion teaches us that a body at rest cannot set itself in motion, and that a moving body cannot change either the direction or speed of its motion, and that if any of these changes take place it is a proof that the body is acted upon by some external force. In the language of science, a force is said to do *work* on a body when *it produces or maintains motion of any kind against resistance.* Merely supporting a weight is not doing work, for there is no motion produced. Under the term "motion" we must understand the visible motion of sensible masses as well as the invisible motion of the particles of a body. Hence, as will be understood better after other chapters have been read, heat produces motion and does work by moving the particles of a body so as to make it expand, and the electric current does work when it decomposes water or any other compound body. Work, therefore, in its widest sense, is the production of visible motion against resistance, or the production of any physical or chemical change. The mechanical work done by moving bodies against the attractive force of the earth is the simplest kind of work, and this work is measured in units called *foot-pounds.* A foot-pound is the amount of work done when a weight of 1 lb. is raised through a vertical height of 1 foot. If we raise a weight of 45 lbs. through a height of 7 feet, we do $45 \times 7 = 315$ foot-pounds of work. The measure of the work done by a force, therefore, is the product of the force into the space through which the body is moved *in the direction of the force.* We may say—

$$\text{Work} = \text{force} \times \text{space}$$

but we must be careful to remember that *space* means the

distance through which the body is moved in the line of action of the force. If the body be displaced, not in the direction of the line of action of a force, but at some angle of inclination to it, then the distance in the line of action of the force must be calculated or obtained by geometrical construction. When a heavy body is raised along a smooth inclined plane, the work done against gravity is measured by the product of the force into the vertical height of the plane, for gravity acts vertically downwards (par. 46). If a body be moved along a horizontal plane, no work is done against gravity, but work is done against the resistance of friction.

As just explained, there are many other kinds of work besides that of moving heavy bodies. Breaking a stick or tearing paper is work done against the resistance of cohesion; heat does work upon a body internally by causing its molecules to have a more rapid vibratory motion, and externally by causing it to expand; and an electric current does work when it overcomes the force of chemical attraction and decomposes water into oxygen and hydrogen.

50. **Energy.**—*Energy is the power of doing work possessed by any body or system of bodies;* that is, it is that condition of a body which makes it capable of overcoming resistance of any kind. A body may possess energy either because it is in motion, or because it is in a position of advantage in consequence of work that has been spent upon it to place it in that position. A falling weight possesses the power of doing work, and has therefore energy, for it can move wheels or break asunder the particles of a sheet of glass on which it falls. Consider now a weight of 14 lbs. on the floor; it has no power of doing work, and is therefore devoid of energy. Now lift it up and place it on a shelf 10 feet high. In doing so work has been done upon it, but the work is not lost; it is stored up in the stone, and will be given back when the shelf is withdrawn and the stone allowed to descend. The stone on the floor had no energy, but the stone even at rest on the shelf had energy, for work had been spent upon it, and it was kept in its position of advantage only by the shelf preventing the action of gravity. The energy possessed by bodies is therefore in

one of two forms or states: (*a*) Energy of motion, called also Kinetic or Actual Energy; (*b*) energy of position, called also Potential or Static Energy.

The kinetic energy of a body is its power of doing work in consequence of the actual motion of the body or of its molecules.

The potential energy of a body is its power of doing work in consequence of its position of advantage, or the position of advantage of its molecules.

A coiled spring possesses potential energy in consequence of the position of advantage relative to each other occupied by the coils; while, when uncoiling and setting wheels in motion, the energy of the spring is kinetic.

51. **Examples of the Kinetic Energy of Visible Motion.**—

Experiment 25.—Place a small weight on a piece of tissue paper stretched across a ring. The weight presses on the paper, but has not enough energy to tear it. Raise the weight about 2 feet and drop it, and its energy of motion now overcomes the resistance of the paper, and therefore does work.

In a similar way we shall find that a thread which will support a weight at rest will be broken by the increased energy of the falling weight attached at one end, and that the energy of visible motion possessed by a falling weight fastened by a string to a spring-balance extends the spring of the balance more than when the weight hangs without motion. Other examples of kinetic energy are found in moving water that is able to turn a mill-wheel, in a vibrating tuning-fork that is setting the air in motion and so sending sound-waves through it, in a heated body whose vibrating molecules send out waves of radiant energy that set air in motion or turn water into vapour. All moving masses or moving molecules possess kinetic energy, that is, a capacity to do work in virtue of their motion.

52. **Examples of Potential Energy.**—Whenever a body is raised to a height against the action of gravity, it possesses in its elevated position a stored-up power of doing work termed Potential Energy, or Energy of Position. This is the condition of a raised weight or a head of water in a reservoir. Similarly,

whenever a body is in a state of strain in consequence of work done upon it it possesses, in consequence of the position of its molecules, potential energy. A coiled or stretched spring, a mass of compressed air in a gun, and a bent bow all possess potential energy, for they are all in a position to do work. As the body at a height falls to a lower position, or as the strained body recovers its size and shape, its energy becomes kinetic, and it gives up again the work that has been done upon it in order to place it in its position of advantage.

53. **Transference of Energy.**—Energy is often transferred from one body to another. When a body in motion strikes another at rest, a part of the motion possessed by the first body is transferred to the second, that of the first body being proportionately diminished. Kinetic energy or energy of motion has therefore been transferred from one body to another.

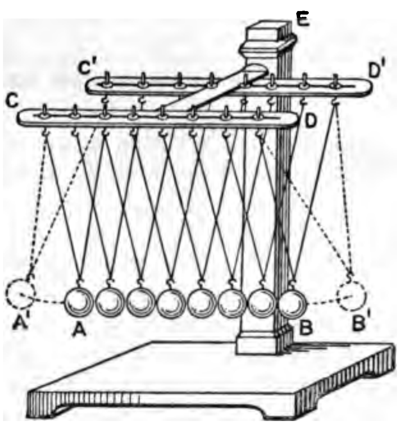


FIG. 48.—Transference of energy through elastic balls.

Experiment 26. — Suspend from two parallel bars attached to a pillar E a row of ivory balls so as to be in contact. Raise one of the balls, A, and let it strike against its neighbour. Its energy of motion is at once given up to the ball which it strikes, and this energy is immediately transferred to the next, and so on through the row until the last, B, having no body to which to communicate its energy, moves off with the velocity of A (Fig. 48).

Potential energy may also be transferred from one body to another. A coiled spring may be made to raise a weight, and in so doing the spring loses potential energy, and the raised mass gains it.

Again, the potential energy of one body is often passing to another and becoming changed into kinetic, or *vice versâ*. Examples of this transference and change will shortly be seen.

It must be noted that in these transferences of energy there

is no loss of energy, only a change of form. A body hurled to a certain height possesses at its highest point no energy of motion (kinetic energy), but it possesses energy of position (potential energy) just equal to the energy of motion that sent it up. When it falls down it reaches the ground with the same speed as it started its upward motion with, and during its fall it could furnish the same amount of work as was expended in raising it.

54. **Heat is a Form of Energy.**—Heat is a form of energy due to some invisible motion of the molecules of a body among themselves, and not of the body as a whole. When a falling body strikes the ground its visible kinetic energy disappears, but it has not been lost. It has been converted into the energy of heat and the energy of sound, and the sum of these different forms of energy is equal to the whole visible energy of motion possessed by the stone when it strikes the ground. The energy of sound consists of moving particles of air, but the energy of heat consists in increased motion of the molecules of the body manifested as increase of heat. Since this invisible molecular motion called heat is able to perform work, we call heat a form of kinetic energy.

As examples of the transformation of the visible energy of motion into heat, the following experiments may be performed:—

Experiment 27.—Hammer a piece of lead smartly several times upon an anvil, and test the temperature of the lead and the hammer before the experiment and after. An increase of temperature can be detected by means of a thermopile and a galvanometer. An iron nail may be hammered until its rise of temperature can easily be felt.

Experiment 28.—Place a small piece of German tinder at the end of a stout glass fire-syringe (Fig. 49). Now introduce the tight-fitting solid piston and force it down quickly. The suddenly compressed air becomes so hot that the tinder is ignited. Mechanical motion is converted into heat.

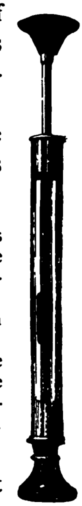


FIG. 49.—A fire-syringe.

Many other instances of the production of heat through rubbing, pressure, filing, grinding, etc., might be given. The visible energy of motion can therefore be transformed into heat.

It should also be noted that the energy of heat is often *being changed into the* visible energy of motion. Every

locomotive engine supplies an example of this transformation. As another example of the disappearance of heat when motion is produced, note this experiment:

Experiment 29.—Let air or other gas that has been compressed in a cylinder and allowed to come to the ordinary temperature escape against the bulb of a sensitive thermometer, and a fall of temperature will be noticeable.

55. **Electrical Energy.**—Various bodies, such as sealing-wax, vulcanite, and glass can be brought by rubbing (*i.e.* by doing work upon them) into a condition such that they attract other bodies near them. This condition is called *electrification*, and the bodies are said to be *electrified*, or to be charged with electricity. Since electrified bodies can produce motion and heat, they are said to be endowed with electrical energy.

Experiment 30.—Rub a piece of sealing-wax or vulcanite with a piece of dry flannel, and then bring it over some bits of light paper, straw, or pith. These will be attracted even at a short distance. The electrified wax does work in raising the bits, and must therefore be endowed with energy.

Experiment 31.—Suspend a pith ball by a silk thread to a support, and bring it between an insulated metal plate joined to the knob of an electrical machine and a metal plate having metallic connection with the earth. The pith ball moves backward and forward between the two metal plates.

FIG. 50.—Particles attracted by a rubbed rod of glass.

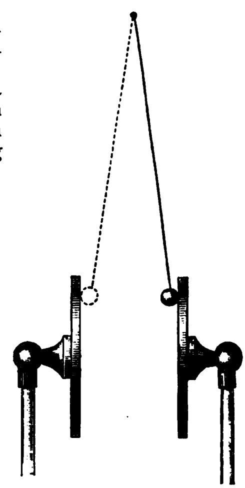


FIG. 51. (*From Joubert's "Electricity and Magnetism."*)

In a charged Leyden jar we have two coatings with opposite kinds of electrification, and on bringing the separate states into

connection, the electrical energy is transformed into heat and light as shown by the spark that passes across the connection.

In the *electric current* produced in a voltaic cell or battery of cells we have electricity in motion. The electrical energy of such a current is partly transformed into heat when it is sent through a thin platinum wire, for the wire offers so much resistance to the current that it becomes red-hot. The energy of the electric current is able to produce motion in a magnetic needle, for if the wire conveying a current be placed over a magnetic needle pointing north and south, the needle is at once moved so as to set itself at right angles to the current.

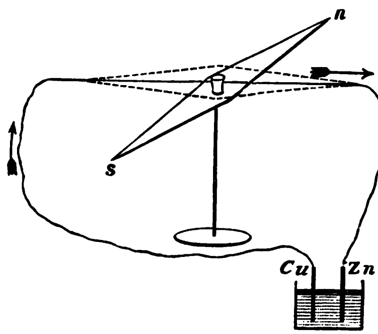


FIG. 52.—Deflection of compass-needle by an electric current.

Not only does the energy of the electric current often get transformed into heat, but heat gives rise to electric currents. If we solder together a piece of antimony and bismuth at one end, and have the free ends united by a thin copper wire, we can detect an electric current passing along the wire on heating the junction. This current would, as just stated, move a small magnetic needle. An instrument applying these facts, and called the *thermopile*, can be made which will measure very small changes of temperature.

56. **The Energy of Chemical Action.**—The carbon of coal and the oxygen of the air have a certain affinity or attraction for each other, and this chemical attraction is a store of energy, the potential energy of chemical separation. When the coal is made to burn, that is, unite with the oxygen of the air, the molecules of the two substances move together, and as the carbon and oxygen unite, the energy becomes kinetic or active, and the potential energy stored in the fuel soon becomes transformed into light and heat. When gunpowder explodes and sends out a 50-lb. ball from a cannon, the energy of chemical

action resulting from the union of the ingredients of the powder is converted into the mechanical energy of visible motion. In a later chapter we shall have many more examples of the energy of chemical action.

57. **Radiant Energy.**—The molecules of a heated body are in a state of rapid vibration, and are constantly communicating some of their energy to the surrounding and all-pervading *ether*. This energy is carried along the ether by means of vibrations or waves, and these ether-waves may either be again transformed into heat, or cause the sensation of light, or give rise to certain chemical actions. Energy transmitted as vibrations of the ether is called *radiant energy*, and the process of transmission is often called *radiation*. What is spoken of as *radiant heat* and *light* are forms of radiant energy (see pars. 72 and 80).

57*a*. **Transformations of Energy.**—It is evident, from what has been said, that one form of energy is often being transferred or converted into another, and it is not difficult to put together a series of interesting transformations. The potential energy of cold fuel is changed as it unites with oxygen during burning in a furnace into the energy of invisible molecular motion called heat; the heat energy of the burning fuel passes into water and changes it into steam; the energy of the steam sets in visible mechanical motion a piston and its connected machinery; the moving machinery may drive a dynamo and produce electric currents; and the electric currents may make white-hot the carbon filament of an incandescent lamp, drive a tram-car, ring a bell, or cook a dinner.

As the student progresses in his studies, those and other transformations will be better and better understood. But it is important to notice even now that the energy which is being dealt with passes into more than one of the other forms, and that the sum of these is equal to the energy applied. There is, in fact, no loss of energy, for energy like matter is *indestructible*. Yet in any change of energy from one form to another, some of it always takes the form of heat, and we cannot convert heat entirely into any other form, but only partially, for some of it is always lost to further use by conduction and radiation.

knows, by means of a thermometer, but a thermometer will not directly measure the quantity of heat contained in a body.

Experiment 32.—Heat equal quantities (say half a pound) of lead and water in the same beaker. The two will reach the same temperature, *i.e.* acquire the same intensity of molecular motion. Now place equal weights of cold water into two beakers, and into one put the hot lead, into the other the hot water. After stirring, it can be noted that the beaker into which the hot lead was put is at a lower temperature than that into which the hot water was added. It is thus proved that the amounts of heat absorbed (or given out) by equal weights of water and lead when heated (or cooled) through the same range of temperature are different.

A similar difference will be found by experimenting with equal weights of other different materials.

59. **Effects of Heat.**—The addition or withdrawal of heat may lead to various changes in bodies. These changes are (1) change of size or volume; (2) change of temperature; (3) change of form or state.

60. **Expansion by Heat.**—The addition of heat causes, as a rule, all substances to expand. The different solids and liquids expand unequally, but all gases expand uniformly and equally. This expansion may be considered in three ways, at least, in solids. When a solid expands it increases in volume; but we sometimes consider the increase in length or linear expansion only, at other times we consider the expansion in area or superficial expansion, while we may at another time consider its expansion in volume or cubical expansion. In gases and liquids we usually refer to cubical expansion only.

The withdrawal of heat from bodies leads to contraction.

Let us now consider the case of *solids.*

Experiment 33.—Cut off a piece of stout copper wire so that it will just pass between two nails driven into a board about 6 inches apart. Using a pair of tongs, heat the wire in a flame, and then try to pass it between the nails. Its length will be found to have increased owing to the heat, as it is now too long to pass between the nails. Let the wire cool, finally placing it on a block of ice. The wire will thus be made to contract so much that it now passes between the nails more easily than at first.

Experiment 34.—Obtain a metal ball of such a size that it just passes through a ring when the two are at the ordinary temperature of the air, and heat it. The ball will now be found to have increased in volume, for it no longer passes through the ring.

Different solids expand unequally for the same increase of

temperature. Thus zinc expands more than silver, brass more than iron, while glass and platinum expand less than any of the above metals, but at about the same rate as each other.

Experiment 35.—Take a compound bar of copper or brass and iron (*i.e.* a bar consisting of a strip of copper or brass and iron soldered or riveted together), and, after hammering it straight, heat it. Notice how it bends owing to the unequal expansion of the two metals, the more expansible metal (copper) forming the outer and longer curve of the bend.

Experiment 36.—Strongly heat a piece of glass rod until the end becomes plastic and soft, and then push in a piece of platinum wire. Allow to cool. The wire will remain fast in the glass as the two substances expand and contract equally. With any other metal the glass would either crack on cooling, or the wire would not remain fixed in it.

The expansion of solids on being heated has often to be taken into account. Rails, for instance, are not placed close together, but a little space is left between their ends so that they may expand in hot weather without meeting. Hot water must be poured into a thick glass vessel with great care, as the

FIG. 53. (*Madan's "Heat."*)

inner layer may expand so much more rapidly than the outer layer as to crack the vessel. For a similar reason, water must not be heated in vessels made of thick glass.

61. **Expansion of Liquids by Heat.**—Liquids, like solids, expand when their temperature rises and contract when it falls, and the amount of expansion or contraction in the case of liquids is much greater than in solids for the same change of temperature. In examining the effects of heat on liquids, we must remember that not only the liquid itself, but also the vessel which holds it, expands and contracts as the temperature changes. The amount of expansion observed, therefore, is somewhat less than the real amount, owing to the small increase of capacity of the containing vessel. The same is true of contraction.

By filling a flask to the brim with water and then heating it, the water soon begins to flow over owing to its expansion.

We can show this expansion of water on heating more by the following experiment :—

Experiment 37.—Fill a flask with coloured water, and then cork having about 18 inches of glass tubing passing a small distanc it. The tube being open at both ends, is seen to rise some distance up it when is pushed in. Fasten a paper scale, div quarters of an inch, behind the tube (see On warming the flask, there is at first descent in the tube, as the heat affects before it reaches the liquid. Then a gr of the water-column in the tube occurs, expands about twelve times more than the same increase of temperature. Witl heat so as to allow the liquid to cool, the contraction that occurs.

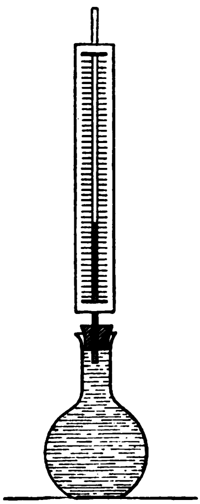


FIG. 54. — Expansion of liquids : a water-thermometer.

The expansibility of other liqu be shown in a similar way, but e be found to have its own rate of ex With an exactly similar flask and may be shown that turpentine i expansible than water, and alcoh expansible than either. To give t same rise of temperature the thre should be placed in the same warm water. Quicksilver, or r has only a little more than h expansibility of water.

62. **Expansion of Gases by Heat.**—Gases are mu expansible than either liquids or solids, and all gases ex the same amount for a given increase of temperature.

Experiment 38.—Fit into the neck of a small flask an in cork through which a piece of glass tubing passes, having its u bent down, whilst its lower end is slightly turned up. Fix th that the end of the glass tubing dips under the surface of water i trough, and, having filled a test-tube with water, invert it over t the tube. Gently warm the air in the flask. Notice that it expa proved by the expelled air being collected in the test-tube.

This experiment may be repeated with flasks filled w gas, oxygen, etc., when the great expansibility of gases w again apparent. If the flasks were all of the same size, fill same extent, and warmed through the same range of tem

by putting them in the same vessel of hot water, the amount of expansion would be the same in all cases. *All* gases, in fact,

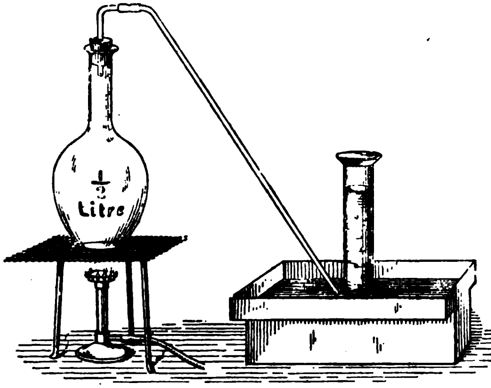


FIG. 55. (*From Newth's "Elementary Practical Chemistry."*)

expand $\frac{1}{273}$ part of their volume for every increase of 1° C. starting from zero, while each solid and liquid has its own rate of expansion. By taking an empty flask and scale similar to one used in Experiment 54 and inverting it so that the end of the tube dips into a vessel of water, the expansion of air may be shown on gently warming the flask, when bubbles will escape through the water. On withdrawing the heat, water will rise in the tube to take the place of the air expelled. Any changes of temperature in the confined air will then be shown by movements of the liquid in the tube, so that this simple instrument may be called an *air-thermometer*.

FIG. 56.—An air-thermometer.

63. **The Differential Air-ther-**

mometer.—A very useful form of air-thermometer to s difference of temperature between two bodies can be : follows :—

Experiment 39.—Bend a glass tube four times at right angles, in Fig. 57. Draw coloured water into the bend, and arrange th the same level in each limb. A ends of the tube to two 2-oz. fl: with good corks. Each cork ı two holes, one for the glass one for a thin stopper of glass ı stoppers are useful for getting ı back to the same level in e: Take two bodies of different ten and put one in contact with e: The expansion of the air in th bulb will depress the column nearest to it, and raise the othe: The differential air-thermomete sensitive, and readily indicates : ferences of temperature of the : flasks.

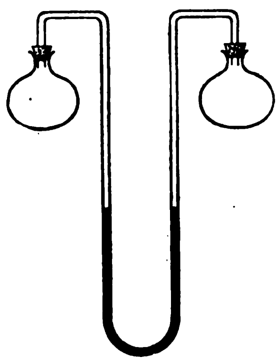


FIG. 57.—A differential air-thermometer.

64.—The Mercurial ' meter.—Since expansion effect of heat which is most and most easily measured, it is chosen as the effect m able for measuring temperature. Liquids are taken their expansion is not only regular, but moderate an observed. Mercury is the liquid most commonly en and the instrument in which it is used to measure tem is called the mercurial thermometer.

To construct a mercurial thermometer we require a gl with a fine bore and having a bulb blown at one end. the mercury to pass down the fine tube into the bulb, th open end of the tube is expanded into a cup, and a little put into this cup. On warming the bulb at the lower is driven out through the mercury, and then some of t passes down into the bulb. By repeating this process and a portion of the tube are at last filled with mercur mercury in the bulb is then heated until it boils and mercury vapour. This drives out the remaining portio air. The bulb and tube are again heated to a point beyond the highest temperature it is intended to meas

while still hot the top of the tube is sealed by the blowpipe. As the mercury cools in the sealed tube it contracts, and leaves a vacuum at the other end of the tube, while the bulb and a portion of the stem are occupied by the liquid. The thermometer now requires to be graduated, *i.e.* marked with degrees or regular intervals. In order to do this it is first placed on melting ice or melting snow, and a mark made on the tube at the point to which the mercury has contracted. This is called the *freezing-point.*

After the freezing-point has been determined, the instrument is placed in the vapour of water boiling at the normal or standard pressure of the atmosphere. The mercury rises, and a second mark is made on the tube at the end of the mercury column. This is called the *boiling-point.* The space between these two marks is then divided into any number of equal parts that may be chosen, and parts of equal length are also marked off some distance below the freezing-point and some distance above the boiling-point. These equal divisions are called degrees, and this division of the thermometer into equal parts is called the *graduation* of the thermometer (Lat. *gradus*, a step or degree). In the Centigrade thermometer the space between the two fixed points is divided into 100 equal parts, 0 being placed at the *freezing-point* and 100 at the boiling-point.

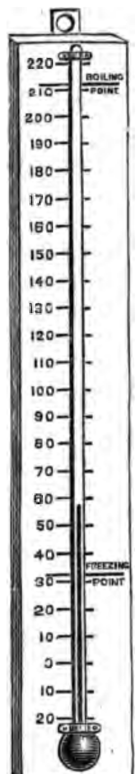


FIG. 58.—Fahrenheit's thermometer.

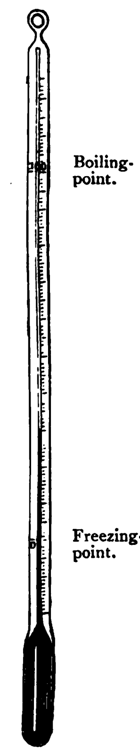


FIG. 59.—Centigrade thermometer.

In Fahrenheit's thermometer the space between freezing-

point and boiling-point is divided into 180 equal parts, 32 being put at freezing-point and 212 at boiling-point. Hence in this thermometer the zero is 32 degrees below freezing-point. This is the thermometer in common use in this country.

In both thermometers temperatures below the 0 are distinguished by having the *minus* sign prefixed. Thus $-6°$ C. denotes 6 degrees below freezing-point on the Centigrade thermometer, and $-6°$ F. denotes $32 + 6 = 38$ degrees below the freezing-point of Fahrenheit's thermometer.

Since 100 divisions or degrees on the Centigrade are equal to 180 degrees on the Fahrenheit, we see that 5 degrees C. = 9 degrees F. Hence it is easy to see how to pass from one thermometer to the other. From C. to F., multiply the number of degrees on the Centigrade scale by 9, divide by 5, and add 32 : $F = \frac{9}{5}C. + 32$. From F. to C., subtract 32, multiply by 5, and divide by 9 : $C = \frac{5}{9}(F. - 32)$.

65. **Reasons for employing Mercury for Ordinary Thermometers.**

(1) It is a liquid that can easily be obtained in a state of purity.

(2) It remains liquid through a great range of temperature, viz. $-40°$ C. to $350°$ C., or $-40°$ F. to $662°$ F.

(3) It quickly transmits heat through its substance, so that it soon acquires the temperature of the body with which it is in contact.

(4) It requires but little heat to raise its own temperature, so that it affects but slightly the temperature of the substance in which it is placed.

(5) It does not wet the glass envelope in which it is put.

The bulb of a thermometer is made large, and the bore of the stem kept small, so that small expansions or contractions of the mercury due to small changes of temperature may be readily noted by the rise or fall of the thin column in the stem. The thinness of the bulb also increases the sensitiveness of the instrument.

Alcohol thermometers are used for measuring very low peratures, and also for what are called *minimum* thermo-

meters. Alcohol is a liquid that has never been frozen at any degree of cold to which the earth is subjected.

Air thermometers are used to measure very slight variations of temperature, as gases expand more than liquids, and also for very high temperatures.

66. **Maximum and Minimum Thermometers.**—The *maximum* thermometer is an instrument used for indicating the highest temperature to which it has been exposed since it was adjusted. Rutherford's maximum self-registering thermometer consists of an ordinary mercurial thermometer placed in an horizontal position, and having a small piece of steel inside the tube *beyond* the mercury.

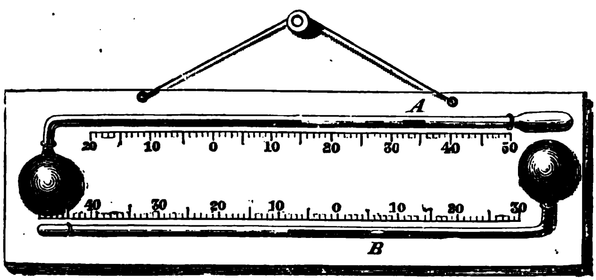


FIG. 60.—Maximum and minimum thermometers fixed horizontally on a rectangular piece of wood. *A*, maximum thermometer, containing mercury, with the index registering 32° C. as the highest temperature attained. *B*, minimum thermometer, containing alcohol, with the index registering 5° C. below zero as the lowest temperature reached.

As the mercury expands with increase of temperature it pushes the steel before it, and as it contracts it leaves the steel in the furthest position to which it has been driven. The end of the steel nearest the surface of the mercury marks the highest temperature since it was last set. The instrument can be prepared for another observation on bringing back the steel into contact with the mercury by means of a magnet.

The *minimum* thermometer is used to indicate the lowest temperature reached since the last observation. It contains alcohol instead of mercury, and *inside* the alcohol contained in the tube there is a *small* index of glass, with the furthest end *touching the surface of* the alcohol. This tube is also placed

horizontally. As the alcohol contracts it carries the index of glass with it, but when it expands the index is left behind. *Thus the end of the index nearest the surface of the spirit shows the lowest temperature.* The index can be again got into position by inclining the tube.

Most maximum thermometers are now constructed to record without an index. A part of the fine tube of the thermometer is drawn out to much greater fineness. As the mercury expands it passes this constriction, but as it contracts it is not able to pass the constriction owing to friction and its cohesion. The mercury therefore remains at the highest point of temperature reached since last set. The thermometer is set by holding the bulb downwards and giving a rapid jerk.

67. **Uses of the Thermometer—Methods of using Thermometers.**—We have seen that a thermometer is used for measuring the temperature or degrees of heat of substances brought into contact with it, but in order to do this accurately certain precautions must be observed. We must take care that the thermometer is only affected by the body whose temperature we wish to ascertain, and that it is neither receiving heat from nor giving up heat to other bodies. We must also allow the thermometer to be sufficiently long in contact with the body to acquire the same temperature. Thus, to ascertain the temperature of a liquid we must allow the bulb and part of the stem to remain in the liquid for a short time. The temperature of the human body may be ascertained by placing a small thermometer in the mouth till it has come into thermal equilibrium with it.

One of the most important uses of the thermometer is to ascertain the temperature of the atmosphere. To do this is a somewhat difficult matter. If we allow the sun to shine upon it, the reading will be too high. Hence, to find out the temperature of the air the thermometer must be in the shade. Here, however, it must not be affected by bodies colder than the air, or the reading will be too low. The air must also have free access to the instrument on all sides. To meet these difficulties, a maximum and minimum thermometer are often placed inside a rectangular screen made of wood louvred

on all sides except the top, and placed on legs in an open space, so that the instruments are about four feet from the ground. They are thus protected from radiation either from the sun or from surrounding objects, and their readings show the highest and lowest temperatures since last set.

68. **Black-bulb Thermometer in Vacuo.**—This is a thermometer constructed, not for the purpose of measuring the temperature of the air, but for measuring the intensity of solar radiation, or the amount of the sun's heat that reaches the layer of the atmosphere where it is placed. It would not suffice to expose an ordinary thermometer to the sun's rays for this purpose, for the bright bulb would reflect and radiate back some of the heat that fell upon it. But when the bulb and part of the stem are coated with lampblack (a variety of carbon) the whole of the sun's rays are absorbed. To prevent loss of heat from this bulb by air-currents and radiation, it is

FIG. 61.—Solar radiation (black-bulb) thermometer.

enclosed in a clear glass tube with a bulb blown at the end, and this outer tube and bulb are exhausted of air. The black-bulb thermometer thus consists of a good maximum thermometer, having the bulb and about an inch of the stem coated with dull lampblack and enclosed in an exhausted glass tube. It is placed about four feet from the ground, and freely exposed to the sun's rays.

The ordinary rule for using the instrument is to notice the maximum temperature indicated during the day, and to compare this with the maximum temperature indicated by the shade thermometer. The *difference* of the two thermometers indicates the greatest amount of solar radiation during that day.

69. **Exceptional Effect of Heat on Water.**—At most temperatures water obeys the general rule, expanding for an increase of temperature, and contracting for a diminution of *temperature, but between* 4° *and* 0° *C. it is an exception to the*

general rule. At a temperature of 4° C. it has its maximum density, *i.e.* a given volume then weighs more than at any other temperature. As it sinks from 4° to 0° C. it gets specifically lighter owing to expanding. That water has its maximum density at about 4° C. can be shown by means of a glass bulb containing a little mercury, and so adjusted that it just floats in water of about 4° C. As the water is cooled or warmed below or above this temperature, the bulb slowly sinks to the bottom. Let us now trace the changes in the volume of water as a quantity is heated or cooled.

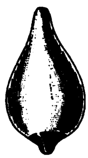


FIG. 62.

As before remarked, if we take a vessel of water and heat it, the water begins to expand until it reaches its boiling-point. It then passes off as vapour, increasing in volume about 1700 times. But before it is all evaporated, take some of the hot water and let it cool slowly, and it can easily be shown that it contracts until it comes near the freezing-point, 39° F. (4° C.), when it begins to *expand*, and continues to do so until the freezing-point is reached, 32° F. (0° C.). Just as it becomes solid it again enlarges, so that ice is lighter than water bulk for bulk.

The specific gravity of ice is 0·92, water being 1. Hence it is that ice forms on the surface and will float.

Water has, therefore, its greatest density and least bulk at 39° F. (4° C.). At 32° F. (0° C.) it freezes. Hence between the temperatures of 39° F. and 32° F. (4° C. and 0° C.) water behaves in an exceptional manner, expanding as the temperature falls from 39° F. to 32° F., and contracting as the temperature rises from 32° F. to 39° F. This exceptional behaviour of water between 39° F. and 32° F. is of great importance in the economy of nature. If water did not expand as the temperature gets near the freezing-point and at the moment of freezing, the whole of the water in a river or lake would increase in density and sink from the surface to the bottom till the whole reached 32° F. It would then become solid throughout, and, instead of having the ice form on the top as it now does, the whole mass would become frozen.

Probably the reason why ice expands at the moment of

freezing is that the arrangement of the crystals in ice (for ice has a crystalline structure) takes up more room than when the water is in the liquid state.

We will now summarize these facts in a tabular way :—

(1) Ice expands from below freezing-point to 32° F. like other solids.

(2) At 32° F. ice melts, and there is contraction of bulk.

(3) From 32° to 39° F. the water still further contracts.

(4) At 39° F. the water has its maximum density or least bulk.

(5) From 39° F. to 212° F. the water expands.

(6) At 212° F. the water boils and undergoes enormous expansion.

(7) Water-vapour expands regularly on being further heated.

The pupil may write out the above table, using Centigrade degrees instead of those of Fahrenheit.

We are now able to understand clearly what takes place when a pond or other sheet of water freezes. The water at the surface is first chilled by the cold air, and this, becoming heavier than the water below, sinks, whilst the lighter, warmer water rises to supply its place. This goes on till the temperature of the whole mass is reduced to 39° F. (4° C.), after which the surface water no longer sinks, for on being cooled below 39° F. the water expands, and, being lighter than the deeper water, remains at the top. This colder water at the surface, being then reduced to the freezing-point, is turned into solid ice floating on the water below, and serves to some extent as a protection from the cold at the surface. The ice formed then slowly increases in thickness in proportion to the intensity of the cold at the surface.

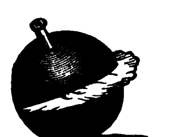


FIG. 63. — Iron shell broken by freezing water.

The great force with which water expands on freezing can be shown by the following experiment :—

An iron bombshell or bottle is filled quite full with water, and then firmly closed with an iron screw. The shell or bottle is then exposed to frost,

and after a time it is heard to burst with a loud noise, and a quantity of ice is forced through the crack as is shown in the figure.

Experiment 40.—Mix together snow and salt, or pounded ice and salt, in about equal proportions. Place a thermometer in the mixture, and notice that the temperature is below the freezing-point of water. Now put into this "freezing mixture" a small bottle full of water and tightly corked. In a short time the water will be frozen and the vessel burst.

70. **Conduction.**—Conduction of heat is the transference of heat through the mass of a body from particle to particle. If we place a rod of iron and a piece of wood of the same length in the fire, we shall soon find that the iron becomes hot at the opposite end, owing to the conduction of heat from molecule to molecule along the rod, while the wood can be held in the hand as it burns away. This simple experiment shows that all substances do not conduct heat equally well, some being good conductors and some bad conductors.

Substances which rapidly pass heat on from particle to particle are called good conductors of heat, those which pass it on slowly are called bad conductors. Most of the metals are good conductors of heat, silver and copper being the two best.

Experiment 41.—Round a brass tube wrap smoothly a piece of paper and hold it in the flame of a gas-burner or spirit-lamp for a short time. Notice that the paper is not scorched, because the brass conducts away the heat of the flame so readily and rapidly. Repeat the experiment, wrapping the paper around a wooden rod of the same size. This time the paper is scorched because wood is a poor conductor of heat.

Experiment 42.—Twist a stout iron and a stout copper wire (of equal thickness) together at one end. At about 4 inches from the joint fasten a marble on each with a little beeswax. Heat the joining of the wires in a Bunsen flame, and notice that the marble on the copper falls first, as copper is a better conductor than iron.

By experiments similar to the last it has been shown that metals are the best conductors of heat, silver being the best of all. A silver spoon left for a minute in a cup of hot tea burns one's fingers, while a spoon of common metal merely plated with silver only becomes warm.

Experiment 43.—Turn on a gas jet, but do not light it. Hold over it a piece of wire gauze. The gas passes through the gauze, and may be lit above the gauze. The flame does not pass below and ignite the gas near the jet, for the iron gauze conducts away the heat so rapidly that the temperature of the gas beneath is not raised to the ignition point (Fig. 64).

This illustrates the principle on which the miner's safety-lamp is constructed.

Liquids are bad conductors of heat, as may be shown by the following experiment:—

Experiment 44.—Hold a test-tube nearly full of water so that a flame plays upon the upper layers of the water (Fig. 65). After a short time the

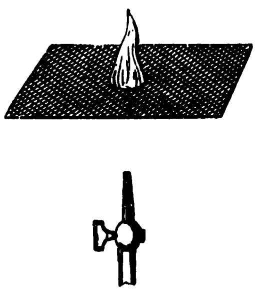


FIG. 64.

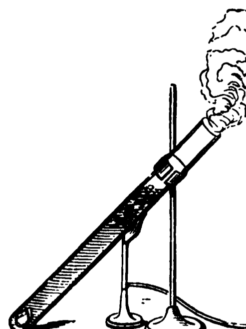


FIG. 65.

water at the top will begin to boil, and yet the bottom of the test-tube feels quite cool. In fact, a piece of ice may be kept weighted down at the bottom of the test-tube without melting, so badly does water conduct heat.

Gases are extremely bad conductors of heat, though it is difficult to show this by a simple experiment, as their particles are always in motion.

Many illustrations and applications of the various conducting powers of different substances can be given. In a room without fire, touch in turn the carpet, the table, the mantelpiece, and the fender. These are all at the same temperature but feel quite different. The sensation given to the skin on touching bodies depends mainly on the conducting power of the substance. The metal fender feels coldest, because the particles touched pass on the heat of the hand rapidly to other particles, so that the hand has its temperature quickly lowered. The stone particles of the mantelpiece conduct heat from the hand less rapidly than the iron particles, so that it does not feel as cold as the fender. The wood of the table is still slower in conducting heat, while the woollen particles of the carpet

scarcely conduct at all. Wool, feathers, cotton, straw, and other organic substances, are all poor conductors. Clothes do not *make* our bodies warm, but only keep them warm, for, being bad conductors, they carry off the bodily heat but slowly to the outside cooler air. Ice can be kept from melting on a warm day by packing it in sawdust or wrapping it in a blanket. Thus a bad conductor may not only keep heat in, but also keep it out.

71. **Convection.**—Convection of heat is the distribution of heat by the movement of the particles of a body from one position to another. It is the general way by which heat is distributed through liquids and gases. It cannot occur in solids, as the relative position of their particles is fixed. The particles of a fluid, after being heated, move away from the source of heat and give place to other particles, for the heated particles, being expanded, become specifically lighter and rise. As just shown, water heated near its surface shows little rise of temperature beneath. If, however, the water be heated at the bottom, it soon becomes warmer throughout. This is not due to conduction, but the particles of liquid near the lamp or fire become heated, expand, and rise to the top. Colder particles descend to take their place, and these in their turn get heated and rise. In this way ascending and descending currents are formed, and the heat is spread through the whole mass. By introducing small pieces of blue litmus these currents can be rendered visible. The air is heated in this way by contact with the warm earth, and the heated air, becoming specifically lighter, ascends, and these convection-currents are the cause of winds.

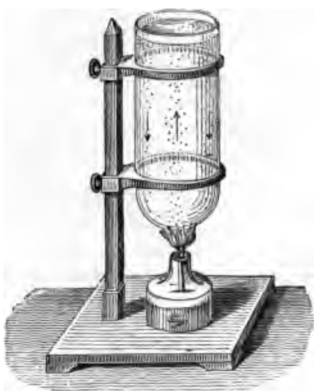


FIG. 66.—Convection currents formed during the heating of water.

72. **Radiation.**—There is a third important way in which

heat passes from one place to another. The sun's heat, for example, reaches the earth neither by conduction nor by convection, but by a process called radiation. Radiation is a wave-motion transmitted through the elastic and subtle medium that fills all space and which is called the ether. "Radiant heat is the same thing as what is called light, only perceived by us through a different channel. The same radiation which when we become aware of it by the eye, we call light, when we detect it by a thermometer, or by the sensation of heat, we call radiant heat." Heat, therefore, is said to pass by radiation from one body to another when the body warmed is separated from the source of heat by some other medium, as the air or the all-penetrating ether. The medium itself may not be warmed at all. The radiant energy (par. 57) from the sun passes through dry air without warming it to any great extent, and is then absorbed by the earth. The heated earth then passes it on to the air in contact with it.

It is the radiant heat from a fire that warms us as we stand before it, for the air between us and the fire is but a bad conductor of heat. Every hot body is sending out radiant energy in all directions, whether the body be luminous, like a jet of gas, or non-luminous, like a vessel of hot water. Two classes of waves of radiant energy are thus distinguished—those which produce both light and heat effects (luminous heat-rays), and those which produce heat effects only (obscure heat-rays), though the waves themselves are of the same kind and differ only in wave-length. When waves of radiant energy fall upon any body a portion is usually *absorbed* and produces heat in the body, while another portion is *reflected* or thrown back from the surface. Some substances, however, absorb or reflect but few waves of radiant energy, for they *transmit* or allow the greater part to pass through them, though few substances readily transmit both luminous heat-rays and obscure heat-rays. Thus water-vapour transmits the former, but absorbs the latter.

It is important to notice that in the process of radiation the heat does not pass *as heat* through space, but as a form of wave-motion called radiant energy, and this radiant energy is con-*verted into heat, or light,* or electricity according to the nature

of the substance that receives it. The molecules of a heated substance are in a state of rapid vibratory motion, and this motion appears to be communicated to the subtle, all-pervading, imponderable ether, through which it is propagated in straight lines (rapid to-and-fro wave-motion) with enormous velocity. The vibrations of the ether on their way are not heat nor light, but a form of energy called "radiant energy," that may be transformed into heat and light again on meeting a suitable body. The vibration-waves in the ether that are convertible into heat are sometimes called radiant heat, or *obscure heat-rays*, while those that may affect us as both light and heat are often called *luminous rays*. But the two kinds of waves are of the same kind and differ only in length of wave, and many luminous waves may produce heating effects as well. All waves of radiant energy are reflected or refracted just as light is, and the laws of reflection and refraction will be explained in the chapter on Light.

73. **Quantity of Heat.**—The temperature of a body measures the intensity of the body's heat or its degree of hotness, but it is not a measure of quantity of heat, for a gallon of boiling water has the same temperature as a pint of boiling water, though it is plain that eight times the amount of heat was necessary to raise the gallon of water to the boiling-point as that required to raise the pint of water. In order to measure the amount or quantity of heat required to produce some change in a body, we must adopt some quantity of heat as the unit quantity. *The unit quantity of heat is the amount of heat required to raise the temperature of* 1 *lb. of water* 1° *C.*

To raise 2 lbs. of water 1° C. it will require 2 units of heat, to raise 6 lbs. of water 3° C. 18 units of heat will be required, and so on. It is thus easy to see how to calculate the amount of heat required to raise the temperature of a given mass (weight) of *water* through a certain number of degrees. Of course the same amount of heat is given out when the temperature falls through the same range.

If we mix two equal masses of water at different temperatures, the new temperature is the mean of the two temperatures. Thus 1 lb. of water at 40° mixed with 1 lb. at 90° gives us a

mass of 2 lbs. at a temperature of $\frac{40+90}{2} = 65°$. With different weights of water, it is easy to calculate the temperature of the mixture by dividing the total number of units of heat by the total weight. Thus 3 lbs. of water at 16° C. mixed with 5 lbs. at 56° C. will give us 8 lbs. at 41° C. For 3 lbs. at 16° has 48 units of heat above 0° C., and 5 lbs. at 56° has 280 units; $48 + 280 = 328$, and $328 \div 8 = 41$.

So far we have only spoken of mixing certain weights of the *same* substance. Let us now try mixing *different* substances. Mix 1 lb. of water at 100° with 1 lb. of mercury at 40°. Instead of a mean temperature of 70° we get a temperature of 98°, so that 2° which the water loses by cooling from 100° to 98°, *i.e.* 2 heat units, suffices to heat an equal weight of mercury 58°, viz. from 40° to 98°, so that 1 unit of heat will raise the temperature of 1 lb. of mercury 29°. Again, mix 1 lb. of water at 100° with 1 lb. of turpentine at 40°, and the resulting mixture will have a temperature of about 80°, *i.e.* 20 units cf heat, which the water loses, raise the temperature of the same weight of turpentine 40°, or 1 unit of heat will raise 1 lb. of turpentine 2°. Hence we see that the same quantity of heat will raise 1 lb. of different substances through different ranges of temperature; and conversely equal weights of different substances in cooling through the same range of temperature give out different quantities of heat. The fact that different substances require different quantities of heat to raise equal weights through the same temperature, or that they give out different quantities in cooling through the same temperature, is expressed by saying that the *capacity for heat* varies in different substances.

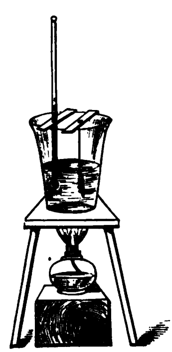


FIG. 67.

Experiment 45.—Fasten a piece of lead weighing 1 lb. to a string, and suspend it in a beaker containing 1 lb. of cold water. Heat the water until a thermometer shows that it is boiling. The hot water and the lead in it will thus be brought to the same temperature, 100° C. Provide two other beakers containing equal weights of cold water, and put the hot lead into *one of these, and the* equal weight of hot *water into the other. Stir* and note the temperatures. It will be found

that the temperature of the 2 lbs. of water is much higher than the ture of the water into which the hot lead was placed. There mι fore, have been more heat required to raise the 1 lb. of water tι than to raise the 1 lb. of lead to 100° C., *i.e.* water has a greater for heat than lead.

Experiment 46.—Heat four balls of about equal weight, a of different metals, to the same temperature (about 150° C.) in an Place them, by means of hook taneously on a thick cake of bees' they cool through the same tem the iron ball melts most wax, as sinking deepest. The copper bal next, then the lead, while the bisı melts least. This experiment shι of these four metals, iron has thι capacity for heat and bismuth the

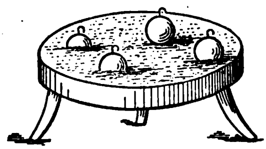


FIG. 68. (*Cumming's "Heat."*)

By comparing the amounts of ice which different ho can melt in cooling down through the same range of t ture to the freezing-point we can compare the relative cɛ for heat of such bodies.

74. **Specific Heat.**—The unit quantity of heat is that ι which raises 1 lb. of water 1 °C. Experiments shι this same quantity of heat will raise the temperature of any other solid or liquid substance more than 1° C. other solid or liquid substance requires so much heat a unit weight through 1° C., water is said to have a capacity for heat than any other solid or liquid. The for heat of any other substance compared to the capa heat that water has, is called the *Specific Heat* of t stance. This comparison or ratio can be put in the fι form :—

$$\left.\begin{array}{c}\text{Specific heat of}\\ \text{a substance}\end{array}\right\} = \frac{\text{no. of units of heat req. to raise 1 lb. of sub}}{\text{no. of units of heat req. to raise 1 lb. of w}}$$

Calling the specific heat of water 1, it follows, from have said, that the specific heats of other substances wil than 1. Here is a table giving a few samples of heats :—

Water, 1.	Mercury, 0·03.
Iron, 0·114.	Turpentine, 0·47.
Copper, 0·095.	Ice, 0·50.
Silver, 0·057.	Steam, 0·50.
Lead, 0·03.	Air, 0·25.

The great specific heat of water, that is, the fact that water takes, weight for weight, much more heat to raise its temperature 1 degree than any other substance, and gives out much more heat in cooling 1 degree than any other substance, is of great importance in nature. Nearly three-fourths of the earth's surface is covered with water, and this is constantly either absorbing the sun's heat or giving it off to the overlying air. Hence water acts as a great equalizer of climate for all places near the sea, while districts in the interior of a continent show much greater variations of temperature at the different seasons of the year.

75. **Solids show no Change of Temperature during Melting or Fusion.**—Solids begin to change into liquids at a definite temperature, called their melting-point, and during this change of state heat is absorbed without rise of temperature. The reason of this is that during a change of state, the heat-energy that is being given to the body is expended in doing work instead of increasing temperature—it is used up in moving apart the particles of the body.

Experiment 47.—Take a block of ice and place it in a vessel. The ice may be below freezing-point, say at 10° C. Apply heat slowly, keeping a thermometer in contact with the ice. The temperature of the ice rises to 0° C., which is its melting-point. Continue the heat whilst stirring, and notice that the thermometer remains at 0° C. until the ice is entirely melted, when it again begins to rise.

This experiment shows that in order to change ice into liquid water a certain quantity of heat is used in overcoming the attraction of the molecules of the ice, and in moving them into different positions. As this heat is not sensible, that is, does not affect the thermometer, it was formerly said to become *latent*, or hidden. The expression *latent heat* is still kept, though we now understand what has become of it. Experiment shows that if we add 1 lb. of water at 80° C. to 1 lb. of ice at 0° C., and take care that no heat is lost, we shall get 2 lbs. of water at 0°. This shows that 80 units of heat are consumed in melting 1 lb. of ice. The *latent heat of water*, *i.e.* the latent heat of the fusion of ice, is therefore said to be 80 thermal units.

Other solids, as sulphur, tin, etc., also melt at a definite temperature, *and then absorb* heat without rise of temperature *during melting or fusing.*

When a liquid loses heat its temperature falls to a certain point, and then the liquid becomes solid. During freezing or solidification the solid gives back the same quantity of heat that was required to change it from a solid to a liquid. The temperature at which a solid, on warming, melts, is under ordinary conditions the same as the temperature at which the cooling liquid solidifies. Water freezes at 0° C. (32° F.), and ice melts at 0° C., so that 0° C. may be called the *melting-point* of *ice*, or the *freezing-point* of *water*. Water at 0° C. has been described as ice at 0° plus the latent heat of melting. The great latent heat of liquefaction of ice produces in nature results as important as the high specific heat of water. Ice and snow require so much heat to become liquid that when a thaw sets in there is no sudden large flood, but a slow continuous melting for some time. On the other hand, so much heat must be given out as the water becomes solid, that lakes and rivers freeze very slowly.

76. **Change of Volume during Solidification.**—Most liquids contract on solidifying and increase in volume on liquefaction. Thus liquid wax, on becoming solid, shrinks about 4 per cent. and when melted lead is poured into a narrow mould a hollow is formed at the centre as the liquid solidifies. Ice, as already mentioned (par. 69), is an exception to the above law. When water solidifies it expands about 9 per cent., and on liquefying it contracts.

Experiment 48.—Nearly fill a flask with lumps of ice, and then fill up with water. Put in a cork provided with a piece of glass tubing 12 or 15 inches long (Fig. 54), and notice the point to which the column of liquid rises in the tube. Place the flask in tepid water, and observe how the liquid column sinks as the ice melts, and thus shows the contraction of volume that is taking place.

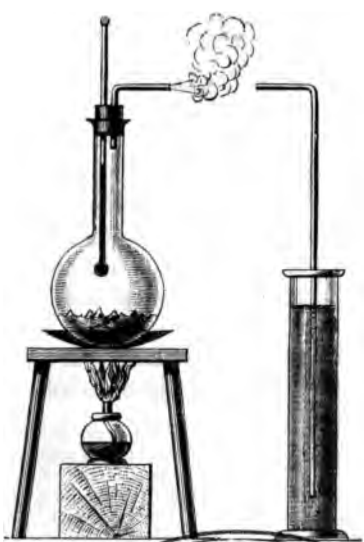
77. **Liquids show no Change of Temperature during Boiling.**—Liquids boil under ordinary conditions at a definite temperature, and during this change of state heat is absorbed without further rise of temperature. Thus when water is heated in a vessel open to the air its temperature rises to 100° C., and then the water begins to boil, as is shown by the bubbles of steam that form within the liquid and then escape at its surface. The temperature at which a liquid under ordinary

atmospheric pressure gives off vapour freely is called its *boiling-point.* While boiling, the temperature remains the same until the whole of the water has boiled away, the heat that is absorbed during ebullition being consumed in doing work upon the molecules of the substance.

This *latent heat of vaporization*, as it is often called, is very great in the case of steam, for 1 lb. of water requires 540 units of heat to convert it into steam. All this heat is given out again during the process of condensation.

It should be noticed that a liquid slowly gives off vapour from its surface at all temperatures. This change of a liquid into vapour at a temperature *below* the boiling-point is called *evaporation.*

Experiment 49.—Take a large flask provided with a rubber cork having two holes. Through one of the holes pass a thermometer, and into the other fit a piece of glass tubing bent at right angles. About half fill the flask with pure water, insert the cork, and then heat the water until it boils. Push the thermometer down into the boiling water, and notice that the temperature of the boiling water remains fixed. Raise the thermometer into the steam from the boiling water (as shown in the figure), and observe that it shows the same temperature as the boiling pure water, viz. 100° C. Now obtain a cylinder of water, B, and a piece of glass tubing as shown in the figure. Connect the two pieces of glass tubing with an indiarubber tube, and pass the steam from the boiling water into the cold water. The steam condenses at once with a crackling sound, owing to the sudden collapse of the steam-bubbles, and the cold water rises in temperature very rapidly, owing to the large amount of latent heat of steam that is set free. If the passage of steam be continued, the cold water will soon be raised to the boiling-point, when no more steam will be condensed, as it will pass away in bubbles through the water as fast as it enters.



78. **The Boiling-point of a Liquid is dependent or Pressure at its Surface.**—When a liquid is boiling, the pre exerted by its vapour is equal to the pressure on the surfa the atmosphere in which the boiling takes place. It fol then, that if boiling takes place under an increased atmosp pressure, water will be above 100° C. when it boils; if un diminished atmospheric pressure, water will boil at a temperature than 100° C. In the experiment just desc when the steam is passed into cold water, it has to overcc greater pressure than when it can escape freely into th and this increases the boiling-point. If the steam be p into mercury to the depth of ab inches, the boiling-point may be raised about 7 degrees.

FIG. 70.

Experiment 50.—Take a round-bo flask and boil water in it till the air is e and the flask filled above the water with only. Remove it from the flame and cork it. After boiling has ceased, pou water upon it. This condenses some water-vapour, and thus lowers the pres the surface of the liquid. Boiling re-com under the diminished pressure.

79. **The Latent Heat of Vap tion.**—Whenever water or any liquid is being converted into va heat is absorbed during the process. During evaporation, no special source of heat is being applied to the liquid, th is mainly obtained from the liquid that is evaporating, s this liquid and whatever it touches becomes colder. experiments illustrate this cooling effect of evaporation.

Experiment 51.—Take two thermometers showing the same rature. Drop upon the bulb of one some of the liquid called eth as this evaporates, observe the fall of temperature owing to the evap ether withdrawing heat from the bulb and from the mercury in the b

Experiment 52.—Upon a block of dry wood put a spoonful of and place a beaker containing a little ether in this water. Blow i beaker with bellows to hasten the evaporation of the ether. So mu will be withdrawn from the beaker and the water beneath it by th evaporation of the ether, that the beaker becomes frozen to the bloc

Many other examples of the cooling effect of evapo

might be given. Fanning the skin when moist with perspiration is a common method of cooling the body. Watering the roads in summer not only allays the dust, but cools the ground and the air near it. Porous bottles are used in hot countries, so that the evaporation of the liquid from their outside surface may keep the contents cool.

The heat used up in converting a liquid into a vapour becomes potential heat-energy, and reappears as kinetic heat-energy sensible to a thermometer when the liquid cools again.

Experiment 53.—Heat a kettle of water, taking the temperature with a thermometer from time to time. Notice that at 100° C. the water boils. Continue the heat, and notice that the temperature ceases to rise. The heat that is being applied after boiling has begun is being used up in turning the water into steam. Let the steam escaping from the spout fall on a cold slate or other object, and notice how hot the cold object becomes as the steam condenses upon it. It is heated by the heat given up by the steam as it changes its condition and passes into the liquid state.

CHAPTER IX.

LIGHT.

80. **Radiation.**—The heat-energy of a body at a high temperature consists of some kind of vibratory motion of the material molecules of the body. This molecular vibration of a hot body is transformed into energy of vibration of the surrounding ether through which it is transmitted at the enormous rate of 186,000 miles a second by a process called *radiation.* The energy of vibration possessed by the ether is termed *radiant energy* (par. 72), and this radiant energy, on meeting certain bodies, may again be transformed into heat and light, or may produce chemical changes, the different effects depending on the length of the vibrations (undulations) of the ether. The vibrations are propagated through the ether in straight lines in all directions, the movement being transverse or across the line in which motion takes place. Each separate set or line of vibrations is called a *ray,* so that according to their effect we speak of rays of radiant heat, rays of light, and chemical or actinic rays. The undulations of comparative great wave-length give rise to the sensation of heat only, and are sometimes spoken of as *obscure heat-rays;* the undulations of medium wave-length may not only produce heat-effects, but can affect our eyes as *light;* while the waves of short wave-length (less than $\frac{1}{67,000}$ inch) produce no light-effects on our eyes, but act chemically on compounds of silver.

Light, therefore, is a portion of radiant energy, and consists of those minute vibrations of the ether which, acting upon the eyes, render visible the objects from which the vibrations proceed. As it consists of vibrations of the invisible ether it is *itself invisible.*

81. **Rectilinear Propagation of Light.**—Light travels in straight lines as long as it is passing through the same homogeneous medium. (A *medium* is any substance through which light can pass, and it is said to be *homogeneous* when it has the same composition, structure, and density throughout.) Though light itself is invisible, we can often trace the path of light-rays by the dust-motes that are illumined as it passes through a chink into a shielded space, and this path is always a straight line. If light-rays had a bent direction in the air, we could see round a corner.

Experiment 54.—Take three cards and make a fine hole through each. Place them a short distance apart, one behind the other, and with the three holes in the same straight line. Place a candle in front of the first, and, on looking through the third, we see light from the candle. On moving any one of the cards aside, no ray from the candle reaches the eye.

The inversion of the images of objects by rays of light that pass through small apertures proves that light travels in straight lines.

Experiment 55.—Fit up a small tube or box to form a "pin-hole camera." At the front is a small hole, and at the hinder part there is a movable screen of tissue-paper or ground glass. Place in front of the pin-hole any small illumined object, and an inverted image of the object will be seen on the screen. Push the screen nearer the pin-hole, and notice that the size of the image diminishes; draw the screen further back, and the size of the image will increase. From the point *o* rays proceed in all directions, but only the ray *ao* can pass through the hole and illuminate the point *a′* on the screen, and *a′* is in a straight line with *a*. Similarly with the ray that passes through *o* from *b*. Each other point of *ab* also produces its image on the screen, so that the total result is an inverted image of *ab*.

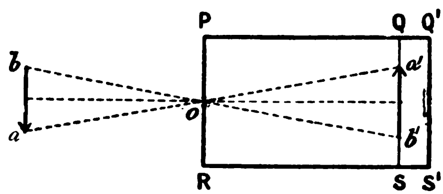


FIG. 71.—Pin-hole camera, showing how the inverted image of the arrow AB is produced by the rectilinear rays of light. QS, movable screen.

Diffused light is produced by an overlapping of images, as would be shown by pricking other holes in the front of the camera, until the images of a candle become so numerous that the screen would be illuminated all over.

82. ***Shadows.***—*It is* in consequence of light travelling in

straight lines that a dark space or shadow is formed behind ar opaque body placed in the path of a beam of light. The nature of the shadow will depend on the size of the luminous body.

If the source of light be a point, or very small, as a pin-hole through the cap of an optical lantern, the rays from the poin

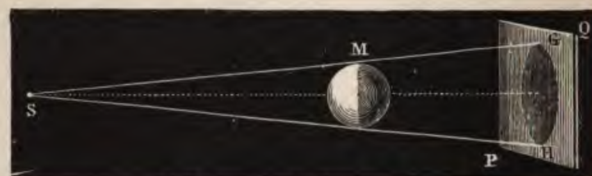


FIG. 72.—Shadow from point of light.

form a diverging cone, so that an opaque object cuts off the light entirely from a space behind it. This space, marked out by lines from the luminous point to various points of the object, receives no light at all. The dark space, or a section of it upon any surface, is called the shadow of the opaque object. If the source of light, however, is of considerable size so that rays are proceeding from many points of a luminous object, we get behind an opaque object a central part called the *umbra* on which no light at all falls, and a surrounding par called the *penumbra*, which gets light from some part of the luminous object. The size and nature of these two spaces wil

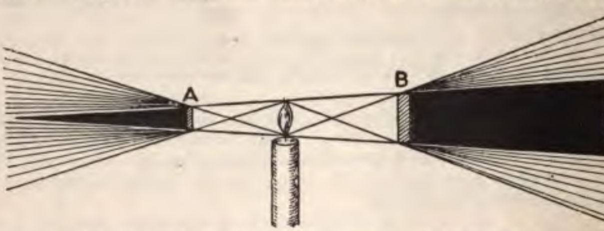


FIG. 73.—Illustrating the formation of umbra and penumbra with an opaque objec smaller than the luminous body and with an object larger than the luminous body.

depend on the relative sizes of the luminous object and the opaque body, as shown in Fig. 73. With an opaque objec *less than the* luminous body, the umbra form a cone tha

comes to a point behind; with an opaque object larger than the luminous body, the umbra cone increases in width with the distance behind.

83. **Reflection of Light.**—When rays of light fall upon the surface of an opaque object, part of the light is absorbed, and part thrown back or reflected. When the surface is a smooth plane surface, like that of a mirror, or the surface of a liquid, reflection takes place in a regular way. With rough, uneven surfaces, the light reflected is scattered irregularly, and it is this irregularly reflected light that renders the object visible.

For smooth plane mirrors the law of reflection is—

The angle of incidence is equal to the angle of reflection, and the incident and reflected rays are both in the same plane, this plane being perpendicular to the reflecting surface.

By the "angle of incidence" is meant the angle which the incident ray makes with the normal (perpendicular) at the point of incidence; by "the angle of reflection" is meant the angle which the reflected ray makes with the same perpendicular. The law may be proved in the following way:—

Experiment 56.—Obtain a cardboard semicircle divided into degrees, and place a mirror L at its centre. Deflect a ray of light by means of another mirror M, so that it falls on the mirror L at the foot of the per-

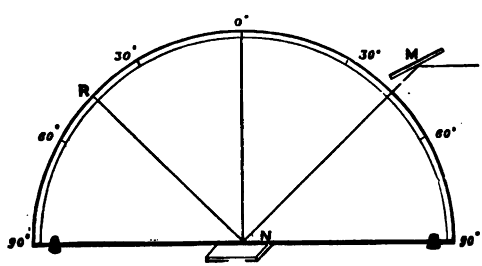


FIG. 74.—Reflection of a ray of light from a plane mirror.

pendicular OL. The reflected ray NR will be found to make the same number of degrees with the perpendicular ON that the incident ray MN makes with the perpendicular. Send a ray along the perpendicular ON, and it will be reflected along NO.

84. **Reflection from a Rotating Mirror.**—If we send a ray of light, NI, perpendicularly upon a mirror, M, it is reflected

according to the law of reflection along itself in the direction IN. If now, without changing the incident ray, we turn the mirror into a new position, M′, the normal to its surface is now IN′. The mirror has been turned through the angle MIM′, which is equal to NIN′. The incident ray NI, falling on the mirror in the position M′, is reflected along IR so that the angle NIN′ is equal to RIN′. While, therefore, the mirror has turned through the angle NIN′, the reflected ray has turned through the angle NIR, which is double the angle NIN. Hence, *when a mirror is made to rotate through any angle, the reflected ray rotates through twice that angle.*

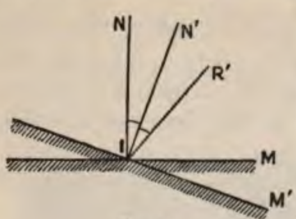


FIG. 75.

85. **Images formed in Plane Mirrors by Reflection.**—The images seen in looking-glasses and other plane mirrors are

FIG. 76.—Image formed by reflection from surface of still water.
(*From Ganot's "Popular Natural Philosophy."*)

formed according to the law of reflection just stated, the reflection of the light taking place in ordinary mirrors from the layer of metal at the back of the glass. Each reflected

pencil of light-rays prolonged behind the mirror meets in a point at the same distance behind that the object is in front; and, as we always see objects in the direction of the light that reaches the eye, the image formed by a plane mirror is always seen at the same distance behind the mirror that the object is in front.

The surface of still water forms a horizontal mirror, and reflected images of objects can therefore be seen in smooth ponds, the reflected image being inverted as each point of the image is as far below the mirror as the actual point is above the mirror.

86. **The Refraction of Light.**—When a beam of light passes from one medium into another of different density, as from air into water or glass, if it falls on the surface of the second medium obliquely, it is bent or refracted out of its original direction.

Experiment 57.—Arrange a vessel of water, into which a little soap has been rubbed so as to render the light that passes into it more visible, upon a table in a darkened room, and send a beam of light upon the surface of

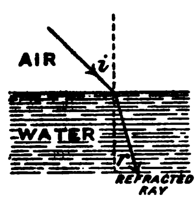


FIG. 77.—*i*, incident ray; *r*, refracted ray.

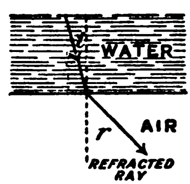


FIG. 78.

the water at different angles. When it falls obliquely it is seen to take a new direction on entering the water. A similar bending, but of different amount, would be seen with other liquids.

On examination of various experiments, it will be found (1) that when light passes from a rarer into a denser medium, it is refracted at the surface of separation *towards* the perpendicular at the surface; (2) that when light passes from a denser to a rarer medium, it is refracted at the surface *away* from the perpendicular to the surface.

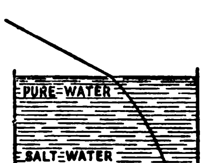


FIG. 79.

The denser *the new* medium is, the greater is the amount

of refraction. Thus salt water is denser than fresh water, and a ray of light passing from air into fresh water is refracted towards the perpendicular, and then, on passing into a deeper layer of salt water, it is further refracted (Fig. 79).

As a consequence of refraction, a river or vessel of water appears less deep than it really is, and the position of any object in the water appears to be nearer the surface than it really is. This effect of refraction is shown in Figs. 80, 81. In Fig. 80, the ray of light SI, that comes from the point S on leaving the water, is refracted at I away from the perpendicular, so that its apparent position is in the direction AIS′. In

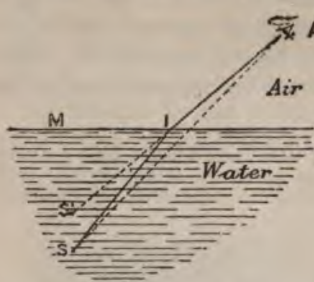


FIG. 80.—Refraction of ray SI, and apparent rise of point S to S′.

FIG. 81.

Fig. 81, the small diverging pencil of rays from the point A is shown, and not merely a single ray, and the prolongation backwards of the rays refracted at B meets at A′ situated above A, so that the point A appears to be raised.

Various common appearances and effects are accounted for by refraction.

Experiment 58.—Place a coin in an empty basin, and stand back so that the coin is just hidden by the basin. Let some one pour water into the basin, and the coin will become visible. The reason will be understood from Fig. 81. The light that enters the eye from the coin is bent away from the normal to the water-surface, but to the eye it seems to have come in a straight line.

Experiment 59.—Hold a pencil or small stick in a vessel of water, and notice that it appears bent upwards on looking along the stick, as the light from each point of the stick in the water is refracted on passing from the water into the air, and the immersed portion is thus brought nearer the eye.

Experiment 60.—Take a thick sheet of plate-glass or a cube of glass, and place it over a sheet of paper on which are marked straight and curved lines. Look at these lines obliquely (Fig. 82), and notice that where the

FIG. 82.

FIG. 83.

glass intersects them they appear broken as a result of refraction. Look down upon them perpendicularly (Fig. 83), and they show no broken appearance as before, but only appear to be raised beneath the glass.

When air or water through which light is passing is of unequal density owing to unequal heating, the refraction thus produced often produces a flickering or streaky appearance on objects seen through it.

87. **Refraction through a Prism.**—In physics a prism is a wedge-shaped, transparent body through which light can pass.

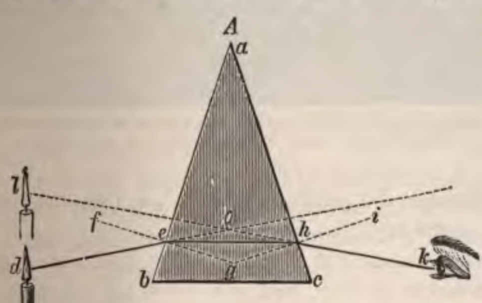


FIG. 84.

When light passes through a prism it suffers a double bending, according to the laws of refraction already stated. Fig. 84

will explain this. The ray of light *de* from the candle, on entering the triangular prism, is bent nearer to the perpendicular, *eg*, in the prism, and it passes along *eh*. On leaving the glass at *h* and passing into the rarer air, it is bent away from the perpendicular, *hi*, and passes along *hk*. An eye at *k*, therefore, sees the candle-flame at *l* in the direction of the line *hk*. The angle between the original and final direction of a ray of light

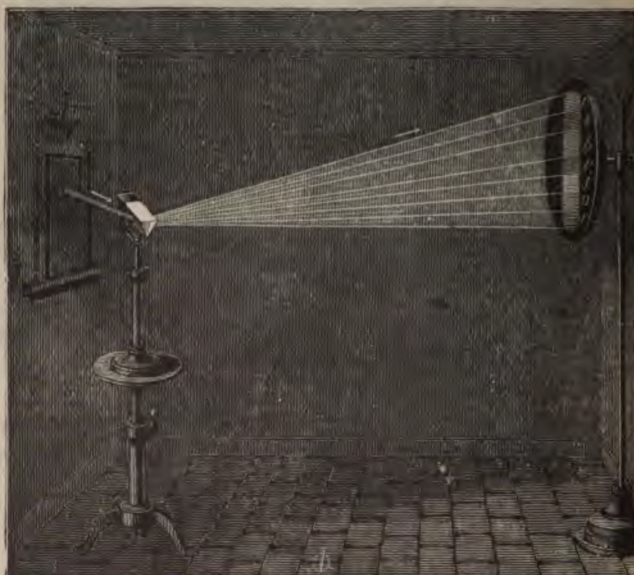


FIG. 85.—Decomposition of white light into the colours of the spectrum by passing a beam of sunlight through a prism in a darkened room and receiving the spectrum on a screen.

passing through the prism (angle *dol* in Fig. 84) is called the *deviation* of the ray.

A prism always acts so as to cause a deviation of a beam of light towards its base, and any object seen through it always appears displaced towards the edge or vertex of the prism.

Objects seen through a prism are not only displaced, but are seen with coloured fringes, so that there is not only a bending of the light, but a breaking-up or dispersion of it. If the

light is monochromatic, *i.e.* consists of one of the simple colours, there will only be a bending or refraction.

88. **Analysis of Light by a Prism.**—When the white light, from the sun, from an electric arc, or other very hot body, is sent through a prism, it not only undergoes refraction, but it is separated, owing to the unequal refraction of the various waves in it, into a band of colours called a *spectrum.* The colours of the prismatic spectrum are often denominated red, orange, yellow, green, blue, indigo, and violet; but there is no sharp line of separation, the various tints passing gradually into one another.

Experiment 61.—Into a dark room let sunlight or light from a lantern pass through a narrow horizontal slit, and it will be noticed that it forms a bright spot on the wall where it falls. Now place a prism with its edge downwards and its base horizontal in the path of the beam. The path of the light-beam is deviated from its original course towards the base of the prism and upon a screen placed to receive the deviated beam a vertical band of colour is seen (Fig. 85). White light is thus shown to be a compound of different coloured rays, and these different coloured rays, being unequally refracted by the prism, give rise to the continuous band of colour termed the spectrum.

Fig. 86 shows a section of a prism with the base upwards, and PQ represents a narrow beam of white light. On entering the prism the beam is refracted towards the base, and the various constituents of the white light are seen to be refracted unequally, so that there is not only refraction but dispersion of the light. On leaving the prism there is again refraction, and the light received

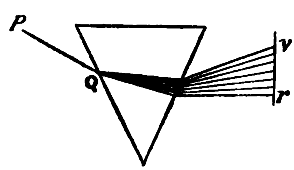


FIG. 86.—Diagram showing formation of a spectrum.

on the screen shows red at one end of the spectrum and violet at the other. It is the red rays that are least bent, and the violet rays that suffer the greatest refraction. The intermediate rays of orange, yellow, green, blue, and indigo being refracted between in this order.

That white light is really compounded of different colours is proved not only by the prismatic *analysis* of such light, but by the fact that the prismatic colours, when recombined, form white *light by synthesis.*

Experiment 62.—Place behind the first prism which has dispersed the white light into the spectral colours a second similar prism in the reverse position, as shown in Fig. 87. This second prism, refracting the coloured band unequally towards its base, just neutralizes the effect of the first prism, and the issuing beam E is white and parallel to the first beam S.

FIG. 87.

Experiment 63.—Upon a circular piece of cardboard paint sections of prismatic colours in the same order and proportion as they occur in the spectrum. Such a cardboard is often spoken of as Newton's disc. The centre is usually left black. When such a disc is rapidly rotated, the effect on the eye is the same as if it received the impression of all the colours simultaneously, and a sensation of white or a greyish-white is produced.

We have thus learnt (1) that ordinary white light is not simple in composition, but a compound of seven various colours


FIG. 88.
—Newton's colour disc.

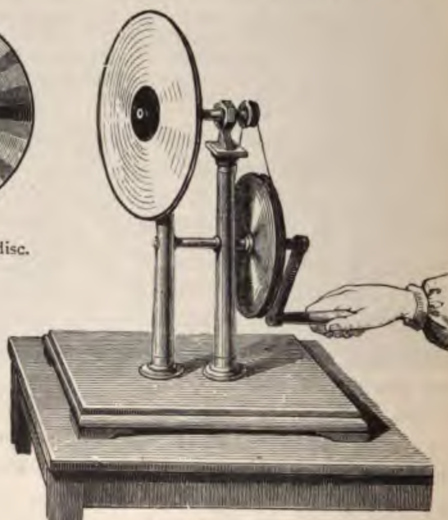


FIG. 89.

that gradually blend into one another—red, orange, yellow, green blue, indigo, and violet; (2) that white light can be dispersed by a prism into a coloured band or spectrum showing these colours *gradually* passing into one another; (3) that the cause of this

dispersion of white light is the different amounts of deviation which the different tints undergo by refraction in the prism; (4) that the red rays are the least refrangible—orange, yellow, blue, indigo, and violet being the order of increase in refrangibility of the others; (5) that the seven spectral or rainbow colours can be recombined by synthesis to again form white light.

Light, in fact, consist of ether-waves propagated from a luminous body, and these ether-waves are not of the same length, the difference of wave-lengths making itself known to our eyes as difference of *colour.* Red is caused by light-waves of greatest length, and violet by light-waves of shortest length. Beyond the red are ether-waves of longer wave-length that produce heating effects on being absorbed, and beyond the violet are ether-waves that can produce chemical effects.

89. **The Colour of Bodies.**—Strictly speaking, colour is a sensation, being the resultant effect upon our organs of sight of the rays of light (or ether-waves) that come from the object seen. Consider first the case of *opaque* objects. The light by which such objects are seen is the light which they reflect after having slightly entered their surfaces. A certain cloth or flower on which white light falls is red because it absorbs most of the green, blue, and violet light, and throws back nearly all the red waves, so that the waves that produce the sensation of red largely predominate. A white object appears white because it sends back the different components of white light in the same relative proportion that they exist in sunlight. An object appears black when it sends back to our eye practically no light, but absorbs all kinds of rays so fully that it appears dark. In the case of coloured *transparent* objects, we see them by the light which they *transmit.* A blue glass appears blue because in the passage of light through it, most of the red, orange, and green rays are quenched in the passage, and in the rays transmitted the blue largely predominate.

What has been said above applies to objects seen in sunlight or other white light. Coloured objects seen in coloured light appear dark unless the light is of the same tint as the natural colour of the object. In a photographer's "dark room,"

for example, into which only yellow and red rays are allowed to enter, a piece of red or yellow ribbon will appear nearly natural, as these are the light-rays that they can throw back or reflect, while other coloured objects appear black. White paper or the hands appear red, as only red rays fall on them, and red they can reflect.

Various experiments can be made to illustrate the colours of natural objects.

Experiment 64.—Obtain a long spectrum upon a screen, as in Experiment 85. Hold various coloured objects in the different parts of the spectrum. A red ribbon in the red portion appears red, in the orange it looks a dull orange, but in the other parts of the spectrum it appears nearly black, as it can only reflect the wave that produces the sensation of red and similarly with other coloured objects. Each is bright when held in its own colour, and becomes dark in parts of the spectrum much removed from its colour, as it is incapable of reflecting the light there. The colour, in fact, is not in the body, but in the light waves that it reflects.

Experiment 65.—Allow the white light from a small hole in a shutter or from a hole in a lantern-cap to pass through a blue solution of sulphate of copper in a glass cell, and note the blue colour received on a screen. Now interpose a piece of red glass before the cell, and notice the extinction of colour, the red glass stopping the blue rays, so that practically no light passes through the two.

Experiment 66.—Obtain sheets of cardboard of various brilliant colours. Send the whole light from the lantern upon these in a darkened room, and catch the reflected light on a white screen. Each coloured sheet reflects on to the white screen its own colour only. A white sheet would reflect any colour, and a black sheet none.

CHAPTER X.

INTRODUCTORY CHEMISTRY.

90. **Elements and Compounds.**—Chemistry is the science which treats of the *composition* of bodies, *i.e.* of the different kinds of substances of which the various pieces of matter are made up. Although the substances found on the earth are so numerous and varied, yet the chemist divides them into two classes only, elements and compounds. Everything we meet is either an element or a compound, or a mechanical mixture of these. *An element is a simple substance, consisting of only one kind of matter.* It cannot be split up or decomposed into different substances, nor can it be built up out of different substances. Thus *carbon* (of which pure charcoal is a variety) is an element, because nothing but carbon can be obtained from it. It is indecomposable. For the same reason the gas called oxygen and the liquid metal mercury are elements. But carbon can be made to unite with oxygen by the force of chemical affinity, and a compound called carbonic acid, or carbon dioxide, is then produced. This union is brought about whenever carbon burns, for this burning results from the carbon uniting with the oxygen of the air and forming the invisible gas called carbonic acid gas. Hence carbonic acid is a compound substance, for it consists of two kinds of substances, oxygen and carbon, chemically united. Water is a compound formed by the union of two gases, oxygen and hydrogen. Limestone is a compound also, and contains three elements, calcium, carbon, and oxygen, united together. *A compound*, then, is *a substance formed of two or more elements united together by the force of chemical affinity*. There are only *about 70 elements known*, but there are many thousands of

I

compounds. *Binary* compounds are compounds formed by the union of *two* elements. Thus carbonic acid and water are binary compounds. *Ternary* compounds are compounds formed by the union of *three* elements, as limestone. Many other examples of both these classes will presently occur. Some compounds contain more than three elements. As already stated, the power which causes the various elements to unite with one another in order to form compounds, and which holds them together after they are united, is called chemical attraction or chemical affinity.

91. **Chemical Symbols and Formulæ.**—Instead of writing the full name of each element and compound, the chemist uses a kind of shorthand. Each element has a sign or *symbol*, and this symbol is the first letter (or sometimes the first letter and another) of its English or Latin name. But it is important to notice that this symbol not only stands for the element, but also for a definite quantity by weight of that element. Thus H not only stands for hydrogen, but also for one atom of hydrogen. As hydrogen is the lightest substance known, its atom is taken as the unit, and to it the number 1 is attached. O stands for oxygen, and for one atom of oxygen; and, as oxygen is sixteen times heavier than hydrogen, the number 16 is attached to the symbol O. In the same way C stands for carbon, and for 12 parts by weight of carbon. The symbol Ca is used for the element calcium, the weight of which compared with that of hydrogen is 40. These numbers are called the *atomic* or *combining weights* of the elements, and they represent the relative weights of the elements when hydrogen is taken as the unit. Compound bodies are represented by placing the symbols of the elements composing them side by side. Thus the compound called mercuric oxide consists of one atom of mercury (Hg) united with one atom of oxygen (O), and it is therefore represented thus, HgO. Carbonic acid is formed by the union of one atom of carbon and two atoms of oxygen; hence it is represented by CO_2, the small figure at the right of an element indicating the number of atoms of that element. HgO and CO_2 are called the chemical *formulæ* of mercuric oxide and carbonic acid respectively. A chemical formula, therefore, is the representation of a chemical compound by means of symbols. H_2SO_4 is the chemical formula of sulphuric acid (also called oil of vitriol), and this formula teaches us that it consists of two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen, chemically united. The quantity of any compound which is represented by its formula is spoken of as a molecule. Thus H_2SO_4 represents a molecule of sulphuric acid, and $2H_2SO_4$ represents two molecules. A molecule of an element usually contains two atoms; H_2 represents a molecule of hydrogen.

By means of this shorthand we can also express chemical changes shortly and exactly whenever a chemical action takes place. Chemical actions always produce changes of composition. The sign + placed between two formulæ shows that the two bodies represented have been added together. The sign = is usually employed in the sense of the word "yields" or "produces," and it also implies that the *weight* of the substances taking part in the chemical change is *equal* to the *weight* of the substance or substances produced as a result of the change. Thus when carbon is made t

burn in oxygen, the two substances unite and carbon dioxide is produced. This chemical change is shortly expressed by the following equation :—

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Carbon dioxide.}}{CO_2}$$

When zinc is placed in dilute sulphuric acid, the zinc displaces the hydrogen of the sulphuric acid and sets it free. Expressed in chemical signs, this change is written thus :

$$\underset{\text{Zinc.}}{Zn} + \underset{\text{Sulphuric acid.}}{H_2SO_4} = \underset{\text{Zinc sulphate.}}{ZnSO_4} + \underset{\text{Hydrogen.}}{H_2}$$

Such changes as these are often spoken of as *reactions*, and chemical reactions are usually represented by equations.

92. **Number and Classification of the Elements.**—The total number of elements at present known is about 70, but many of these are rare and seldom met with. Most of the elements are solids at the ordinary temperature of the air, but bromine and mercury are liquids; and oxygen, hydrogen, nitrogen, and chlorine are gases. The elements are divided into two classes, *metallic* and *non-metallic*. The metals are distinguished from the non-metals by their lustre, malleability, metallic ring when struck, and by generally possessing a high specific gravity and being good conductors of heat and electricity.

In the following table is a list of (1) all the non-metals; (2) the common metals. To each is added its symbol and its atomic or combining weight.

Non-metals.			Metals.		
Names of elements.	Symbols.	Atomic weights.	Names of elements.	Symbols.	Atomic weights.
Boron	B	11	Aluminium	Al	27·3
Bromine	Br	80	Barium	Ba	137
Carbon	C	12	Calcium	Ca	40
Chlorine	Cl	35·5	Copper (Cuprum)	Cu	63·5
Fluorine	F	19·1	Gold (Aurum)	Au	196·2
Hydrogen	H	1	Iron (Ferrum)	Fe	56
Iodine	I	126·5	Lead (Plumbum)	Pb	207
Nitrogen	N	14	Magnesium	Mg	24
Oxygen	O	16	Manganese	Mn	55
Phosphorus	P	31	Mercury (Hydrargyrum)	Hg	200
Selenium	Se	78	Platinum	Pt	197
Silicon	Si	28	Potassium (Kalium)	K	39·1
Sulphur	S	32	Silver (Argentum)	Ag	108
Arsenic	As	25	Sodium (Natrium)	Na	23
			Tin (Stannum)	Sn	118
			Zinc	Zn	65

93. Preparation and Properties of Oxygen.—Oxygen gas exists in a free state in the atmosphere, but it is there largely mixed with another gas called nitrogen, the nitrogen forming about four-fifths and the oxygen one-fifth of the air. Pure oxygen can be most conveniently prepared from a white crystalline substance called potassium chlorate, or chlorate of potash.

Experiment 67.—Take a quantity of this substance, powder it in a mortar, and then mix it with about one-third its weight of the dry black oxide of manganese, as this substance, though not changed itself, allows the potassium chlorate to give up its oxygen at a less temperature than would be otherwise required. Place the mixture in a flask, which is then fixed

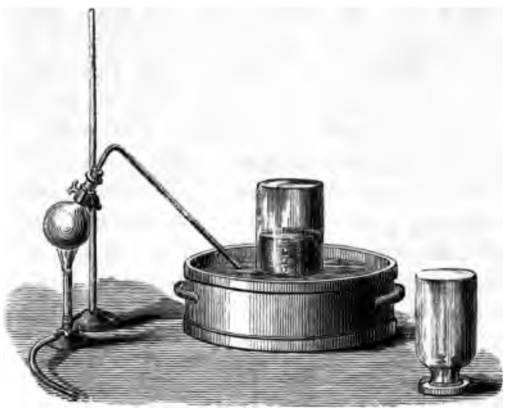


FIG. 90.– Preparation of oxygen.

on a stand. Fit a cork into the flask with a hole in it, through which pass a glass tube bent so that it dips into water in a vessel called a *pneumatic trough*. In the pneumatic trough place a *bee-hive shelf*, having a hole in the side of the shelf for the bent delivery tube to pass into, and a hole at the top of the shelf for the gas to rise through. The top of the shelf should be below the surface of the water in the trough. Fill a glass bottle or jar quite full of water, place a glass plate over the mouth, and invert the jar into the trough and take away the plate. Gently heat the flask, and after waiting a little while until all the air has been driven out, put the gas-jar on to the top of the bee-hive shelf. The bubbles of gas that come off pass up into the bottle and displace the water. When the jar is full, lift it off the shelf, place the glass plate over the mouth, and then take it out of the trough. Collect in this way four or five jars of oxygen gas. The chemical change that has taken place in the flask may be thus represented:

$$\underset{\text{Potassium chlorate.}}{KClO_3} = \underset{\text{Potassium chloride.}}{KCl} + \underset{\text{Oxygen.}}{O_3}$$

94. **Experiments illustrating the Properties of Oxygen.**—After noticing that the gas thus prepared and collected is colourless and without smell, take successive jars and try the following experiments :—

(*a*) Lower a lighted candle attached to a bent wire into a jar of oxygen, and notice that the flame becomes larger and brighter. (*b*) Thrust a long glowing splinter into a jar, that is, a splinter with only a red-hot tip. The wood at once bursts into flame and burns vigorously. (*c*) Take a little sulphur, and put it into a small iron spoon at the end of a bent wire, called a *deflagrating spoon.* Set fire to the sulphur, and notice that it burns with a pale blue flame. Plunge the lighted sulphur into a jar of oxygen, and it will burn much more brightly, though the oxygen itself does not burn. (*d*) Repeat experiment (*c*), using a small piece of phosphorus instead of sulphur. (*e*) Upon a deflagrating spoon put a small piece of wood charcoal (carbon), and heat it in the Bunsen flame until it glows. Plunge the glowing charcoal into a jar of oxygen. The carbon burns with great brilliancy. (*f*) Heat a watch-spring so that it becomes red-hot. It then loses its elasticity, and can be twisted in the form of a spiral after cooling. Fasten one end of this spiral into a piece of cork, and dip the other end

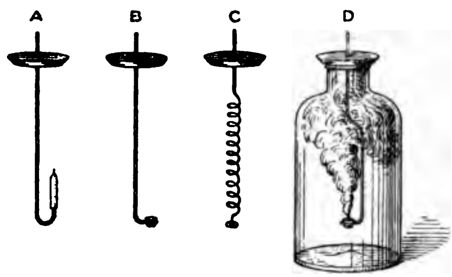


FIG. 91.—Arrangements for combustion in oxygen. A, candle at end of deflagrating spoon ; B, sulphur on deflagrating spoon ; C, coil of watch-spring ; D, phosphorus burning in oxygen.

into a little powdered sulphur. Set fire to the sulphur, and immediately plunge it into a jar of oxygen. The sulphur sets fire to the steel spring, which burns with great splendour, and drops of melted oxide of iron fall down to the bottom of the jar, which should be covered with a little water. After each experiment cover the mouth of the jar with the glass plate or a piece of cardboard. These experiments teach us that *oxygen is a colourless gas that supports combustion, and that substances burn in oxygen with much greater energy than in air.*

It must be carefully noticed that while these different substances have been burning they have not been destroyed; that is, they have not disappeared entirely and gone into "nothing." They have entered into combination with the oxygen, and new substances, called *oxides*, have been produced. No element can be destroyed; it can be made to change its form and enter into new combinations, but it still exists in

some state. Hence matter is indestructible. Wood contains, along with other things, the element carbon, and during the process of burning or combustion this carbon unites with the oxygen to form an invisible gas called carbon dioxide. We represent this chemical action thus:

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Carbon dioxide.}}{CO_2}$$

If we close the mouth of the oxygen bottle in which the splinter or charcoal was burnt, then pour in a little clear lime-water and shake it up, we shall notice that the lime-water becomes milky. This proves that the bottle contains something besides oxygen, for on shaking a bottle of pure oxygen with lime-water no milkiness is produced. The milkiness is caused by the carbon dioxide uniting with the lime in the water to form an insoluble substance called calcium carbonate (Exper. 85).

The jar in which the sulphur was burnt will be found to contain a gas having a pungent smell. This gas is sulphur dioxide, and its production is shown by the following equation:—

$$\underset{\text{Sulphur.}}{S} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Sulphur dioxide.}}{SO_2}$$

On placing a little water in the jar, this sulphur dioxide is dissolved, and the water acquires a sour taste and the power of turning blue litmus red. Bodies possessing this taste and this power are called *acids*. The chemical changes that are produced when phosphorus and iron burn in oxygen may be thus represented:

$$\underset{\text{Phosphorus.}}{P_2} + \underset{\text{Oxygen.}}{O_5} = \underset{\text{Phosphorus pentoxide.}}{P_2O_5}$$

$$\underset{\text{Iron.}}{Fe_3} + \underset{\text{Oxygen.}}{O_4} = \underset{\text{Oxide of iron.}}{Fe_3O_4}$$

Phosphorus pentoxide, which settles on the sides and bottom of the jar as a white powder, dissolves in water to form an acid, like sulphur dioxide does, but iron oxide is not soluble in water.

The metal sodium also forms an oxide, for on being strongly heated, and then plunged into a jar of oxygen, it burns brightly and forms white fumes of sodium oxide that will dissolve in

water. This dissolved oxide, however, has no acid taste. It has a soapy feel, and restores the blue colour to litmus that has been reddened by an acid. Such a solution is said to be *alkaline*.

95. **Oxidation and Combustion.**—The process of uniting with oxygen is called "*oxidation.*" It is a chemical action, and, like most other chemical actions, is accompanied by the development of heat. When the oxidation goes on so rapidly and the heat developed is so great that light is produced, the process is called *burning*, or *combustion*. *Combustion*, therefore, is rapid chemical action attended with the production of heat and light. In ordinary combustion the fuel or substance burnt (coal, coal-gas, wax, tallow, etc.) consists of compounds of carbon and hydrogen. The products of this combustion are two oxides—carbon dioxide, CO_2, and water-vapour, H_2O. What we call "flame" is vapour or gas in the act of combustion.

Oxides, therefore, are binary compounds formed by the union of oxygen with one of the other elements. The experiments just performed with oxygen show that oxides may be divided into two groups. The oxides of one group dissolve in water to form acids. These oxides include the oxides of sulphur, phosphorus, and carbon, and may be called *acid-forming oxides*. The second group is either insoluble in water or dissolves in water to form a solution that restores the blue colour to litmus reddened by an acid. These oxides include iron oxide, sodium oxide, and other metallic oxides, and are spoken of as *basic oxides*, or *bases*.

96. **Preparation and Properties of Hydrogen.**—Hydrogen is another important gas that can be easily prepared and collected, so that its properties may be ascertained.

Experiment 68.—Fit into a flask a cork that has two holes bored in it, and into one of these holes place a piece of tubing having a thistle-shaped cup at the top. Into the other hole of the cork the bent delivery tube is placed to carry the gas off to the pneumatic trough. Before placing the cork into the flask, put in a few pieces of zinc or iron. Fit in the cork with its tubes, and pour sufficient water down the thistle tube to cover the metal so that the end of the tube is under water. Now add a small quantity of sulphuric acid by means of the thistle tube. The metal soon begins to react with the dilute sulphuric acid, and a brisk bubbling or effervescence is caused by the escape of hydrogen gas. After waiting a minute or two

until all the air has escaped, collect two or three jars of the gas in the same way as oxygen was collected. The reaction may be thus represented:

Zn	+	H_2SO_4	=	$ZnSO_4$	+	H_2
Zinc.		Sulphuric acid.		Zinc sulphate.		Hydrogen.

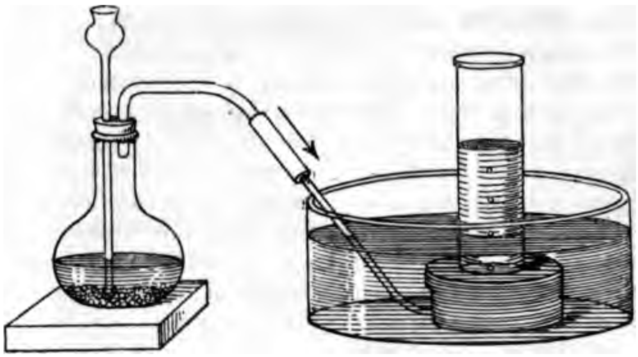


FIG. 92.—Preparation and collection of hydrogen gas.

To illustrate the properties of Hydrogen—(*a*) Notice that the gas is colourless and without smell. (*b*) Hold a small jar full of hydrogen mouth downwards, and push a lighted candle up into the gas; the gas burns at the *mouth* of the jar, but the candle is extinguished. (*c*) The extreme lightness of hydrogen may be shown by passing it into a small collodion balloon. The gas will expand the balloon, and when it is fully distended, detach the balloon from the tube and set it free. It will ascend rapidly through the air of the room until arrested by the ceiling, when after a short time the hydrogen will escape and the balloon descend. This characteristic property of hydrogen may also be shown by pouring the gas *upwards* from one jar to another as in Fig. 93. In a few seconds it will be found that the light hydrogen has passed up into the upper jar, and displaced the air to such an extent that the gas in the upper jar will take fire on applying a lighted taper. The slight explosion shows that some air is mixed with it.

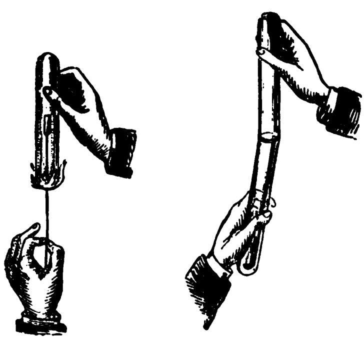


FIG. 93.—Experiments with hydrogen.

97. The very light metals sodium and potassium have such a great affinity for oxygen that they readily decompose water,

combining with the oxygen and setting free the hydrogen. If sodium be dropped upon water, it floats about, becoming less and less till it disappears. A lighted taper placed above the floating sodium kindles the escaping hydrogen. If a piece of the metal be held under the surface of the water by wrapping it in wire gauze, bubbles of gas may be seen passing through the water, and the gas may be collected in a jar previously filled with water. The chemical action that goes on when sodium acts on water may be represented by the equation—

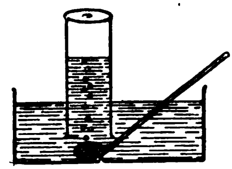


FIG. 94.—Obtaining hydrogen by the action of sodium on water.

$$\underset{\text{Sodium.}}{2Na} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Sodium hydrate.}}{2NaHO} + \underset{\text{Hydrogen.}}{H_2}$$

The sodium hydrate remains dissolved in the water, and it gives to the liquid a soapy feel. It also causes the liquid to turn a reddened litmus paper blue, and is therefore said to have an *alkaline* reaction (par. 108).

Iron is another metal which will decompose water and set

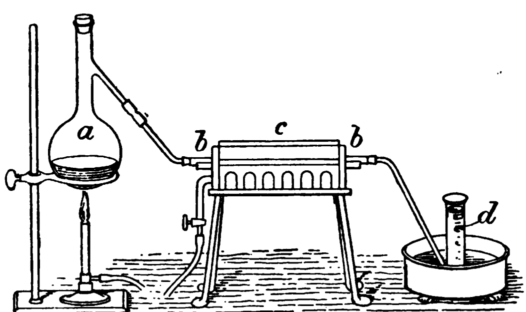


FIG. 95.—Decomposition of steam by red-hot iron.

free the hydrogen, but it must be at a high temperature to effect this. The decomposition of water by red-hot iron can be carried out as follows:—

Experiment 69.—Take an iron tube about 18 inches long and 1 inch in diameter; fill it with small iron nails or bright iron turnings, and place it in a gas *furnace. Heat the* tube to redness, and then connect one end

with a flask and tube in which water is being boiled. Join the to a delivery tube passing into a pneumatic trough. The ste: enters the heated iron tube *bb* is decomposed by the red-hot iron, : uniting with the iron and the hydrogen passing on. This hy collected in a jar, *d*, at the pneumatic trough. The change can sented thus :

$$\underset{\text{Iron.}}{3Fe} + \underset{\text{Water.}}{4H_2O} = \underset{\text{Oxide of iron.}}{Fe_3O_4} + \underset{\text{Hydrogen.}}{4H_2}$$

The oxide of iron produced in this experiment is not the sam rust. It is a magnetic oxide of iron.

In Experiment 68 we showed that hydrogen was bustible gas, although not a supporter of combustic let us repeat this experiment more carefully, so that determine what compound is formed when hydrogen b when it unites with oxygen.

Experiment 70.—Put into a flask a few pieces of granulated fit into the neck of the flask a cork having two holes bored tl Through one hole pass a thistle tı bottom of the flask, and through a short bent tube passing throug cork into a thicker horizontal tı latter contains small pieces of chloride, a substance which readil moisture, so that the gas passing it is dried, and we are sure that vapour is carried along with the l The U-tube shown in Fig. 99 i form of drying tube. The tub from the calcium chloride tube : bent at right angles, and its end ‹ to a point. Pour some dilute sulp down the thistle tube, and after tl been escaping some time so th: air is carried out, apply a light t‹ of the drawn-out tube. The burns quietly with an almost flame. Hold over the flame a glass tube about ½ inch internal and notice that the water-vapoı by the combustion of the hydrog densed in drops on the cold sid tube. Thus water is proved to l when hydrogen burns in air. Th of building up a compound (wa its constituent elements (hydrogen and oxygen) is known in ch *synthesis* (Gr. *syn*, together ; and *thesis*, a putting). On mixing o: hydrogen in a stout soda-water bottle in the proportion of one oxygen to two volumes of hydrogen, and applying a light, the unite with a loud explosion to form a drop or two of water.

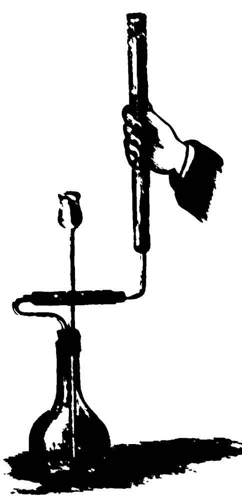


FIG. 98.—Synthesis of water.

98. **Water.**—Water is found in nature in three states or conditions: ice, water, and steam. All three forms have the same chemical composition, the substance being a compound of oxygen and hydrogen—an oxide of hydrogen—represented by the formula H_2O. As already learnt, its physical condition depends on its temperature. Under ordinary atmospheric conditions it is a solid below 0° C. (32° F.), and a gas above 100° C. (212° F.), while between these temperatures it is a liquid (par. 69). Contrary to the general rule, water expands on solidifying, so that the specific gravity of ice is 0·917, water being 1·0. Accordingly ice floats on water. When water passes into invisible vapour, or true steam, it increases in volume about 1700 times. Water-vapour is much lighter than air (0·625 to air 1).

The purest form of water which exists in nature is *rain-water*, though this always contains a little oxygen and carbon-dioxide dissolved from the air. To obtain pure water artificially, any ordinary water is distilled, when all the solids dissolved in it are left behind (par. 6). River water and spring water always contain a small quantity of solid matter, the amount and nature of the dissolved solids depending on the nature of the rocks over which the water has flowed.

Experiment 71.—Evaporate to dryness on a clean piece of platinum foil, or in a clean porcelain dish, a little distilled water, and notice that there is hardly any perceptible residue. With ordinary tap-water the residue is distinctly perceptible.

Experiment 72.—To show that water contains dissolved gas, we must boil the water to expel the gas. Fill a flask to the brim with cold water, and push in a cork provided with a delivery tube. The displaced water drives out the air from the delivery tube and fills it. Pass the tube into a pneumatic trough, and put the flask on a retort-stand. On heating the flask with a Bunsen burner until it boils, the dissolved gases will be expelled, and may be collected in the ordinary way. These dissolved gases are mainly oxygen and carbon dioxide, for the nitrogen of the air is but slightly soluble in water.

It has already been mentioned that water dissolves many solids, and it usually acts as a more powerful solvent when hot than when cold. (Gases, however, dissolve more freely in cold water than in hot water.) Substances, however, differ greatly in their solubility. Some, like sugar, common salt, and alum, are *freely soluble;* some, like gypsum or plaster of Paris,

are *slightly soluble*; some, like chalk and sand (silica), are quite *insoluble*. Water, however, charged with carbon dioxide will dissolve chalk and other forms of calcium carbonate (par. 106).

Experiment 73.—Illustrate the solvent powers of water by weighing out an ounce each of sugar, common salt, and powdered gypsum, and find the quantities of water necessary to dissolve each. These will be 1 oz., 3 ozs., and 360 ozs. respectively, *i.e.* sugar is 3 times more soluble than salt, and 360 times more soluble than gypsum.

When the water containing a substance in solution is allowed to evaporate slowly, the substance often separates out in definite geometrical forms called *crystals*. In some cases these crystals contain a certain quantity of water, which is necessary for the substance to keep its crystalline form. Such water is called "water of crystallization." Copper sulphate (blue vitriol), for example, is found in the form of blue crystals, but if these crystals be heated their water of crystallization is driven off and a white amorphous mass remains, the substance being no longer able to retain its crystalline shape. On moistening the mass with water it again takes up its water of crystallization and turns blue. Some salts lose their water of crystallization and fall to powder on exposure to the air. They are said to "effloresce." Common washing-soda is an example. Other salts absorb moisture on exposure to the air, and are said to "deliquesce." Calcium chloride is an example of a deliquescent salt.

99. **Experiment to prove the Composition of Water by Analysis.**—Analysis (Gk. *ana*, apart; and *lusis*, a loosening) is the breaking up of a compound into the elements that compose it. To analyse water, that is, to separate it into its two elements, we require the aid of electricity from a galvanic battery. Electricity has the power of decomposing water so as to split it up into its constituent elements. The apparatus required is called a *voltameter*, and is shown in the figure. The insulated wires proceeding from a battery of three or four cells pass into the trough, and to the ends of these wires a piece of platinum foil is attached.

Experiment 74.—Fill the trough and the two tubes with water slightly acidulated with sulphuric acid. This is done in order to make the water conduct the electricity better. Invert the two tubes in the trough so that

one of the platinum terminals at the end of each wire is under the mouth of each tube. On setting the battery in action the electricity passes into the water, and gas-bubbles are seen to rise from each slip of platinum, and these collect in the tubes placed to receive them. More gas is given off from one end than from the other; in fact, twice as much gas is liberated from one terminal as the other, so that when one tube is full the other is only half full. Take away the tube first full, keeping the thumb over the end. Invert the tube, quickly remove the thumb, and apply a light. The gas burns with a pale blue flame, showing that it is hydrogen. Now remove and invert the second tube, which is only half full, in the same way. Dip a glowing splinter into this gas. The wood bursts into flame, thus showing that this is oxygen gas. In this way we have proved analytically that water consists of two volumes of hydrogen united to one volume of oxygen.

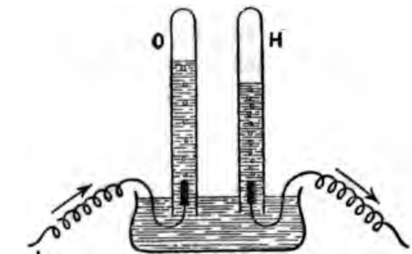


FIG. 97.

100. **The Air or Atmosphere.**—The air is a *mixture* of gases—that is, the gases composing it are not chemically united, but merely in a state of admixture. *Dry* air consists chiefly of the two gases, nitrogen and oxygen; but it also contains nearly 1 per cent. of a gas called argon, about 0·4 per cent. of carbon dioxide, as well as traces of ammonia and a condensed form of oxygen called ozone. Besides these gases, the air always contains a certain quantity of invisible water-vapour. The exact proportions of these gases in 100 volumes of dry air are as follows:—

Nitrogen (including argon)	79·00
Oxygen	20·96
Carbon dioxide	0·04

The argon is included with the nitrogen, as it is a similar inert or inactive gas, and is separated from it with great difficulty. The presence of carbon dioxide in the air may be proved by the following experiment:—

Experiment 75.—Pour a little lime-water into a saucer and leave it exposed to the air for some time. A thin crust of calcium carbonate will then be formed on the surface of the lime-water, this formation of calcium carbonate with lime-water being the chemical test for carbon dioxide.

The amount of carbon dioxide in the air varies slightly, being a little more in large towns than in the country. We have already learnt that when coal and wood are burnt, the carbon in these substances unites with the oxygen to form carbonic acid. A still larger quantity of this gas is supplied to the air by living animals. In breathing, air is taken into the lungs and thence into the blood, and in all our tissues a kind of slow combustion goes on. The oxygen of the air unites with the carbon in the blood, and the carbon dioxide is then expired. Decaying plants and animals also, when freely exposed to the air, give off this gas, and it is one of the gases given off from volcanoes. Seeing, then, that carbonic acid is being supplied to the atmosphere from all these sources, it may be asked how it is that the proportion of it in the atmosphere does not increase. The explanation is that the *green* parts of *living* plants in presence of the sunlight have the power of taking the carbon from the carbonic acid in order to build up their wood and other tissues; plants decompose the carbonic acid, retaining the carbon and setting free the oxygen. The dry air of the atmosphere is always in a gaseous state, and the gases composing it are thus constant in quantity from year to year; and, though the constituent gases have different specific gravities, there is no tendency to separation among them, as gases diffuse uniformly through the space in which their particles are free to move.

Slight quantities of a gas called ammonia are present in the air, and of an active form of oxygen called *ozone*, as well as minute particles of solid matter which appear as dancing motes in a sunbeam lighting up a shady place. But besides the above gases there is always a quantity of water-vapour in the air, and this quantity does not remain constant. We know that when a vessel containing water is heated till it boils, the water is quickly evaporated and passes into the air in an invisible state. But a slow evaporation is going on continually from the surface of every exposed piece of water—from river, lake, sea, and very slowly even from ice and snow. In ebullition or boiling, the bubbles of vapour are generated throughout the mass of the liquid, rising to the surface to escape, but in the

slower process of evaporation the vapour is derived from the surface only. In whatever way, however, the water-vapour is formed, the air shows no visible change on account of the aqueous vapour added to it, for true steam is invisible. The amount of water-vapour present in air varies considerably from day to day, but no matter how warm and dry the day is, there is always some present. This may be proved in the following ways:—

Experiment 76.—Bring into a warm room a tumbler full of ice-cold water. The outer surface of the glass, though at first perfectly dry, soon becomes bedimmed with moisture. The reason is that the air near the cold glass becomes chilled, and, as cold air cannot retain as much vapour as warm air, some of the vapour is condensed and deposited on the sides of glass like dew.

Experiment 77.—Weigh out into a beaker some strong sulphuric acid, or some calcium chloride, and let it stand for some hours. Then re-weigh. The beaker will be found to have increased in weight, owing to the power which sulphuric acid and calcium chloride have of absorbing water-vapour from the air.

100*a*. **Nitrogen.**—From the table of the composition of the air by volume in the preceding paragraph we have learnt that the two chief gases in air are nitrogen and oxygen, and that there is nearly four times as much nitrogen as oxygen. If, therefore, we remove the oxygen from a closed vessel of air we shall have nearly pure nitrogen left.

Experiment 78.—Float a small porcelain crucible, *c*, in a trough of water, and put into it a small piece of dry phosphorus. Set the phosphorus on fire by touching it with a hot wire, and immediately invert over the crucible a bell-jar full of air, holding the jar well under water. The phosphorus, in burning, combines with the oxygen of the air in the jar to form dense white fumes of a binary compound called phosphoric pentoxide (P_2O_5). When all the oxygen has been used up, the combustion ceases. The oxide of phosphorus falls down and dissolves in the water to form phosphoric acid, the water rises in the jar to take the place of the oxygen used up, and the jar remains about four-fifths full of a gas which is quite colourless, as may be seen after all the white fumes have disappeared. This gas is the nitrogen of the air, and therefore contains a little argon. Nitrogen is a very inert gas. If a lighted taper be inserted into the gas, it is at once extinguished, and the gas *itself does not burn.* If the gas is shaken up with lime-water, no change

FIG. 98.—Preparation of nitrogen from air.

takes place, and this distinguishes it from carbon dioxide, which also extinguishes a lighted taper. It seems to serve merely the purpose of diluting the oxygen of the atmosphere, for this experiment shows us that, roughly speaking, ordinary air consists of four-fifths nitrogen and one-fifth oxygen.

That the nitrogen and oxygen of the air are only mixed together, and not chemically combined, may be gathered from the following experiments :—

Experiment 79.—Mix together four volumes of nitrogen with one volume of oxygen. Notice that no contraction takes place. A thermometer placed in them would show that there is also no change of temperature. Since chemical union is always accompanied by a change of temperature, it follows that the two gases have not combined chemically together. Lower a lighted candle into the two gases, and it will be found that the candle burns in the mixture as in common air. Air, therefore, is a mechanical mixture, and not a chemical compound.

Experiment 80.—Invert a large test-tube over mercury, as in Fig. 102, so that it is about three parts filled with air. Pass up into the tube a little strong solution of pyrogallol, and then a small piece of caustic potash. These two substances, when placed together, have the power of absorbing *free* oxygen. Notice that the mercury slowly rises in the tube, owing to the absorption of the free oxygen from the air, as may be proved by testing the residual gas with a lighted taper.

101. **Air and Water.**—We have already learnt that air is mainly a mechanical mixture of oxygen and nitrogen, and that water is a compound of oxygen and hydrogen. We shall now show how the oxygen of the air may be made to combine with a metal, and how the oxygen in combination with a metal may be made to leave the metal and unite with hydrogen to form water.

Experiment 81.—Place some copper turnings, or a roll of copper gauze, in a hard glass tube. Heat the tube strongly while air is gently blown through from a small pair of bellows. Notice that the bright copper becomes black. If the tube and its contents be weighed before the experiment and after, an increase of weight will be found. The copper has been oxidized. It has taken oxygen from the air, and the black substance is oxide of copper—

$$\underset{\text{Copper.}}{Cu} + \underset{\text{Oxygen.}}{O} = \underset{\text{Copper oxide.}}{CuO}$$

To prove that the black substance formed by sending air over heated copper is an oxide of copper, we must perform another experiment—

Experiment 82.—Take the tube containing the blackened copper, support it on a stand, heat it, and send over the blackened mass a stream of hydrogen (Fig. 99), made as in Experiment 68. Steam is found to pass

out at the further end, and this steam, on being led into a cool flask, condenses into water. The copper regains its original colour and weight, for the hydrogen withdraws the oxygen from the copper oxide to form the water that is produced. The process of withdrawing oxygen from a compound is a process of "reduction," and the hydrogen is therefore said to have "reduced" the copper oxide to metallic copper. The last two experiments prove that air contains one of the two constituents of water, viz. the gas oxygen.

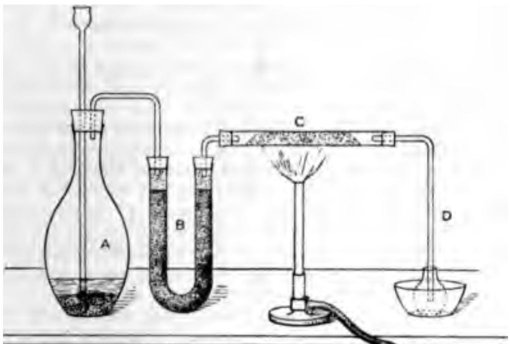


FIG. 99.—A, flask in which hydrogen is being generated; B, U-tube containing calcium chloride; C, hard glass tube containing copper oxide; D, tube leading water into small flask.

102. **Distinction between Compounds and Mixtures.**—We can now distinguish between mixing things together, and causing them to unite together so as to form a new compound. In some few cases elements unite at once on being brought into close contact, but frequently heat, electricity, or some other force must be used to bring about chemical union. If we take some iron filings and sulphur we may mix them together in any proportion, but they do not unite. With a magnifying glass the particles of the iron and the sulphur can be separately distinguished, and by throwing the mixture into water we shall see that most of the heavy particles of iron sink at once to the bottom, whilst the lighter sulphur either floats or sinks much more slowly; or we may dip a magnet into the mixture, and in this way the magnet, which attracts iron and not sulphur, may be made to pull out all the metal and leave the sulphur behind. Now take fifty-six parts by weight of iron and thirty-two parts by weight of sulphur, and heat the mixture in a hard glass tube. After a time you see a deep red glow quickly spread through the mixture as chemical union takes place. If now you examine the material, you will see that you can no longer distinguish the iron and the sulphur separately, nor is the substance any longer attracted by the magnet. A new substance has been formed, having properties different from those of the two elements composing it. This new substance is a chemical compound called sulphide of iron. Notice, then, (1) that in a *mixture* the substances can be separated by mechanical means, and that the substances forming the mixture may be mixed in any proportion, while the properties of a mixture partake of the properties of the substances put together; *(2) that in a compound* the substances unite together so that they

cannot be separated by mechanical means, and the union takes place in certain definite proportions, viz. that of their atomic weights or simple multiples thereof, and that the compound is a new substance, possessing properties different from the elements composing it. Gunpowder is a good example of a mixture. It consists of charcoal, sulphur and nitre ground together, but these substances are not chemically united, for they can be separated by mechanical means. This may be done by shaking up a little gunpowder with water, and filtering. The charcoal and sulphur, being insoluble in water, are left behind on the filter-paper, whilst the nitre, having dissolved in the water, runs through, and can be obtained from its solution by evaporation. Since sulphur is soluble in carbon disulphide, whilst charcoal is not, pour on to the remaining mixture a little of this liquid, and catch it in a test-tube as it runs through. Let the same liquid pass through the mixture two or three times, and then allow it to evaporate slowly away by pouring it into a large watch-glass and letting it stand, when crystals of sulphur are left behind. The charcoal still remains on the filter-paper.

103. **Distinction between Physical and Chemical Changes in Matter.**—If we take a piece of iron and heat it till it becomes red-hot, it is still iron. Hot iron has the same composition as cold iron. If we take the piece of iron and magnetize it with a magnet, so that it will attract other pieces of iron, it is still iron; for magnetized iron has the same composition as iron not magnetized. The changes that the iron has undergone have given it new properties, but they have not altered its composition. Such changes are called *physical* changes, and the physical properties of a body refer to its condition, whether solid, liquid, or gaseous. Hardness, colour, density, crystalline form, and the state of the body as regards its heat and electricity, are physical properties. But wherever there is a chemical change, whether it takes place slowly or quickly, we have a change in *composition*. Thus, if iron be exposed to moist air, it takes up something from the air, and becomes covered with a red substance called rust. Rust is a new substance, of a different composition as well as of a different colour, and with the force of cohesion much less than in the iron; and as it is formed by the chemical union of iron and oxygen, it is a compound. The formation of rust is an example of a chemical change. The only property that chemical action is powerless to alter is that of weight. There is neither loss nor increase of weight in any chemical action, for matter can neither be created nor destroyed. Again, in all chemical changes the elements combine together in fixed proportions by weight. On passing dry hydrogen over a weighed quantity of copper oxide (Fig. 99) and then re-weighing, the loss of weight gives us the amount of oxygen by weight which has been removed to form water. The equation is—

$$\underset{\text{Hydrogen.}}{H_2} + \underset{\text{Copper oxide.}}{CuO} = \underset{\text{Water.}}{H_2O} + \underset{\text{Copper.}}{Cu}$$

If we collect and weigh the water produced, the difference between the weight of water formed and the weight of the oxygen used gives us the weight of the hydrogen that has combined with the oxygen to form the water. As a result of many careful experiments the ratio of hydrogen to oxygen in water is as 1 : 8, *i.e.* water consists of $\frac{1}{9}$ hydrogen and $\frac{8}{9}$ oxygen by weight.

CHAPTER XI.

OTHER COMMON ELEMENTS AND COMPOUNDS.

104. **Carbon.**—Carbon is an abundant element that occurs in the solid condition in three distinct forms—charcoal, graphite, and diamond. *Charcoal* is a soft, amorphous, dull black solid obtained by heating wood and other organic substances out of contact with air. *Graphite* is a soft bright crystalline variety of carbon often called "black-lead." *Diamond* is an extremely hard transparent variety of carbon, its crystals often being octahedral in shape. The specific gravity of charcoal is 1·5, of graphite 2·5, and of diamond 3·3. Though these three varieties of carbon are physically so unlike each other, they are chemically the same substance, for on burning them in oxygen the same chemical compound is produced, viz. carbon dioxide. When an element occurs in forms that are physically dissimilar, but chemically identical, the forms are said to be *allotropic* modifications of the element.

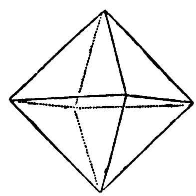


FIG. 100.—Model of octahedron.

Carbon occurs in nature, not only free, but also in combination with other elements to form numerous compounds. It occurs combined with oxygen to form carbon dioxide; it is present, associated with oxygen and lime, in the minerals called carbonates; and it is a constituent of nearly all animal and vegetable matter. Wood, bone, sugar, bread, and coal all contain carbon united with hydrogen and oxygen.

Experiment 83.—Place some chips in a hard glass tube, one end of which is then drawn out as shown (Fig. 101). Heat the tube strongly, and notice that the wood chars or blackens and a volatile oil is driven out, which will burn at the *mouth of the tube.* A large amount of liquid condenses on

the cool parts of the tube. On breaking the tube the blackenec found to contain free carbon. The liquid is mainly water formed hydrogen and oxygen t been expelled. Carbon set free and obtained in way from bread, starc and sugar. The process ing out of contact with illustrated is called d distillation.

FIG. 101.—Preparation of wood charcoal.

Charcoal is very and floats on cold On being placed in water, the air is e from the pores, a charcoal sinks. C has also a great ab power for many ga absorbed gases passi its pores and becoming oxidized by the oxygen of th the pores. It is therefore used as a deodorizer and disir Decomposing animal matter gives off noxious gases, b sprinkled with charcoal the offensive smell ceases. The ing experiment further illustrates sorbing power of charcoal :—

FIG. 102.

Experiment 84.—Fill a large test-t ammonia-gas and invert it over a basin of (Fig. 102). Pass into the test-tube a sm of dry, freshly prepared charcoal. The soon absorbs the ammonia, and the pressu atmosphere on the surface of the mercu basin causes the liquid to rise and fill the

105. **Carbon Dioxide.**—When of charcoal is burnt in oxygen, the and the oxygen unite to form a co called carbon dioxide. The san stance is also formed when any compound is burnt in oxygen or air. Most combustibles that are u carbon compounds, the carbon being united in most ca the element hydrogen.

Experiment 85.—Hold a dry jar over a candle-flame or a burning taper for about a minute. The jar gathers some of the invisible products of combustion. Its sides become bedimmed with moisture formed by the union of the hydrogen in the candle with the oxygen of the air. The jar also contains some carbon dioxide, formed by the union of the carbon in the candle with the oxygen of the air. This can be shown by pouring lime-

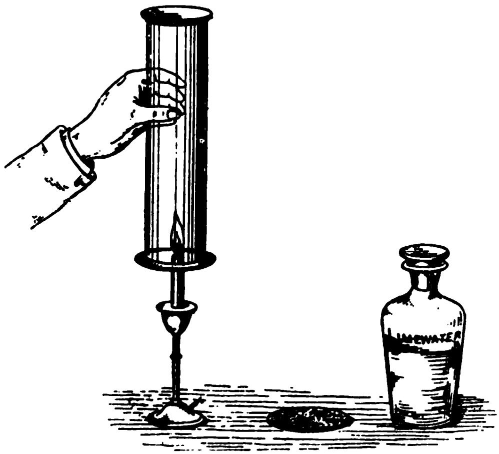


FIG. 103.
(From Newth's "Elementary Practical Chemistry.")

water into the jar and shaking it up. The lime-water is turned milky by the carbon dioxide, owing to the lime uniting with the carbon dioxide to form particles of insoluble calcium carbonate.

In the same way treat the coal-gas flame and the flame of a spirit-lamp, and in both cases it will be seen that carbon dioxide is produced when coal-gas or spirit is burnt.

To obtain a quantity of carbon dioxide for experiments, we generally act upon one of the chemical compounds called "carbonates." Limestone or chalk is a chemical compound called calcium carbonate, and contains three elements—a metal calcium, the solid carbon, and the gas oxygen. Its chemical formula is represented thus, $CaCO_3$. Carbon dioxide can be obtained from any form of calcium carbonate (limestone or marble), either by the action of heat or by the action of an acid. Other carbonates, as magnesium carbonate (magnesite), can be treated in the same way.

Experiment 86.—Place some magnesia alba (magnesium carbonate powder) in a hard glass tube. Fit it with cork and delivery tube, as in

Fig. 104. Support the tube on a stand and strongly heat it. The ca
dioxide driven off may be collected in a small trough in the usual
The magnesium carbonate is split up by the heat into oxide of magne
which remains in the tube, and carbon dioxide which is driven
Powdered calcium carbonate may be treated in this way, but it requ
much greater heat to drive out the gas. The above reaction is as follov

$$\underset{\text{Magnesium carbonate.}}{MgCO_3} = \underset{\text{Magnesium oxide.}}{MgO} + \underset{\text{Carbon dioxide.}}{CO_2}$$

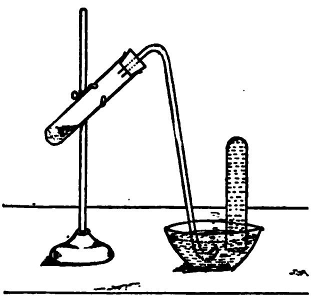


FIG. 104.

FIG. 105.—Preparation of carbon dioxi

Experiment 87.—Put into a flask some pieces of calcium carbon marble, limestone, or common chalk. (The sticks of "chalk" used fc blackboard are not really chalk, but a preparation of calcium sulpl Fit up the flask with thistle and delivery tube as shown in Fig. 105. down the thistle funnel dilute hydrochloric acid until the acid just c the end of the thistle tube. A violent effervescence or bubbling, due t liberation of a gas, soon begins. The gas may either be collected a pneumatic trough or, as it is $1\frac{1}{2}$ times heavier than air, it may be coll by simply allowing it to fall down to the bottom of the jar, ar gradually to lift out the lighter air. This method of collecting a g known as the method of "downward displacement." In order to asce when the jar is full, we make use of the fact that the gas does not su combustion. Insert slowly, therefore, a lighted taper into the jar, an place where it is extinguished will indicate the quantity of carbon di the jar contains.

The following equation represents the chemical change

$$\underset{\text{Calcium carbonate.}}{CaCO_3} + \underset{\text{Hydrochloric acid.}}{2HCl} = \underset{\text{Calcium chloride.}}{CaCl_2} + \underset{\text{Water.}}{H_2O} + \underset{\text{Carbon di}}{CO}$$

106. **Experiments to illustrate the Properties of Ca Dioxide.**—It will have already been noticed that carbon dio is a colourless gas that is neither combustible nor a supp of combustion. A small animal placed in a jar of the g *soon suffocated* for want of *free* oxygen.

(*a*) Pass the gas from the delivery tube into a beaker of water. After a short time test the water with a blue litmus paper. It will be found to be acid. The gas has dissolved in the water to form a feeble acid, *carbonic acid*. The name "carbonic acid" is sometimes applied to the gas itself. Boil the water. The gas is driven out of the solution, and the water is no longer acid to litmus.

(*b*) Pass the gas into lime-water for some time. Note that insoluble calcium carbonate is first formed (see equation), but after a time is redissolved, and the water becomes clear again.

$$\underset{\text{Lime-water.}}{CaH_2O_2} + \underset{\text{Carbon dioxide.}}{CO_2} = \underset{\text{Calcium carbonate.}}{CaCO_3} + \underset{\text{Water.}}{H_2O}$$

This action of carbon dioxide on lime-water is characteristic of the gas.

(*c*) The heaviness of the gas is shown by the way it is collected. It may also be illustrated by pouring the gas from one jar to another, like one pours water. The fact that the gas has changed jars may be proved by lime-water or by testing with a candle.

(*d*) Shake up a little clear lime-water in a large bottle of fresh air. Notice the slight cloudiness produced, proving that air contains a little of the gas. By means of a glass tube breathe into the bottle and again shake. The milkiness produced shows that air expired from the lungs contains much carbon dioxide. In fact, experiment (*b*) can be shown by blowing down a glass tube into lime-water.

It is of great importance to notice that calcium carbonate is insoluble in pure water. If, however, we take some lime-water in a glass beaker, and cause carbonic acid gas (carbon dioxide) to bubble through it for a considerable time, we have seen that, although it becomes milky at first, from the particles of chalk (calcium carbonate) produced, yet, on continuing to bubble in more carbonic acid, it becomes clear. We thus learn that, although, as stated above, calcium carbonate is quite insoluble in pure water, *it dissolves in water which contains carbon dioxide in solution.* On boiling the clear solution thus obtained, the carbon dioxide is driven off, and the calcium carbonate is again precipitated. Rain-water dissolves a little carbonic acid as it falls through the air, and it obtains more as it percolates through ground containing decaying animal and vegetable matter. In this way it becomes able to dissolve calcium carbonate, and in those parts of the country where chalk and limestone rocks abound, parts of the rocks are slowly dissolved away, and the water of the springs and streams contains small quantities of calcium carbonate in solution. Such water is called *hard water*, and when used for washing purposes it only "lathers" with difficulty. Water which contains

no calcium salts in solution, such as pure distilled water, or rain-water as it falls, is *soft water*, and the soap "lathers" easily with such water.

107. **Lime.**—When limestone, or any other form of calcium carbonate, is strongly heated for some hours, it gives off carbon dioxide, and leaves behind a hard white solid which is called lime. This chemical change may be thus represented :

$$\underset{\text{Calcium carbonate.}}{CaCO_3} = \underset{\text{Lime.}}{CaO} + \underset{\text{Carbon dioxide.}}{CO_2}$$

Pure lime is an amorphous white solid, *i.e.* it has no definite crystalline shape. It is remarkable because it cannot be melted or fused even by the oxy-hydrogen flame, which, however, causes it to glow, and so give out an intense white light which is called lime-light. Its chemical name is calcium oxide. Obtain a specimen of lime, so as to perform the following experiments.

Experiment 88.—On a shallow dish place a lump of fresh lime, and slowly pour on to it some water, a little at a time. Notice that the lime is getting hot. In a few minutes steam will be evolved, owing to the large amount of heat produced. This indicates that a chemical action is going on with the lime and the water, and for this reason this solid is often spoken of as *quick lime*. After a short time the lump begins to break up and crumble into pieces, leaving a soft white dry powder which is called *slaked lime*. The change that has taken place can be thus shown :

$$\underset{\text{Quick lime.}}{CaO} + \underset{\text{Water.}}{H_2O} = \underset{\text{Slaked lime.}}{CaH_2O_2}$$

If quick lime is left exposed to the air it slowly "slakes," and at the same time absorbs carbon dioxide. Shake a little of this slaked lime in a test-tube with water for a few minutes, filter or allow to settle, and then test the liquid with a red litmus paper. It will be turned blue, showing that slaked lime dissolves in water to form an alkaline solution. This alkaline solution is *lime-water*. The chemical name for slaked lime and its solution in water is calcium hydrate. Lime-water is much used as a test for carbon dioxide.

Experiment 89.—Take two test-tubes. Dissolve in one a little powdered marble in hydrochloric acid, and in the other a little lime (CaO) in the same acid. Gently warm the two test-tubes until the solids have dissolved, and then evaporate the solutions to dryness in two evaporating-dishes. In both cases a white solid is left, which, on being exposed to the air for some time, deliquesces, *i.e.* absorbs moisture. This white solid is calcium chloride, which can therefore be made by dissolving either calcium carbonate (marble) or calcium oxide (quick-lime) in hydrochloric acid.

108. **Acids and Alkalies.**—Acids are chemical compounds that have a sour taste, turn red litmus blue, and contain hydrogen which can be replaced by a metal. The action of turning blue litmus red is spoken of as an *acid reaction*. The

ounds called hydrochloric acid, sulphuric acid, and nitric exhibit all these properties in a marked degree. We have (par. 96) that when zinc is placed in dilute sulphuric acid, llowing change takes place :—

Zn	+	H_2SO_4	=	$ZnSO_4$	+	H_2
Zinc.		Sulphuric acid.		Zinc sulphate.		Hydrogen.

e zinc displaces the hydrogen in the sulphuric acid.

ne metals, sodium, potassium, calcium, and magnesium, burnt in air or oxygen, form oxides called soda, potash, and magnesia respectively. The first two oxides dis- in and combine with water easily, and the last two are y soluble in water, and their compounds with water are hydrates or *hydroxides*. The compounds of soda and n with water have a soapy feel, and turn red litmus blue. nces that have the power of turning red litmus blue are o have an *alkaline* reaction, and bodies that have this ne reaction, and also the power of neutralizing acids, are *alkalies*. The hydroxides of sodium and potassium, as s that of the compound termed ammonium, are examples nmon alkalies. The hydroxide of sodium (NaHO) is ntly called *caustic soda*, and droxide of potassium (KHO) *potash*.

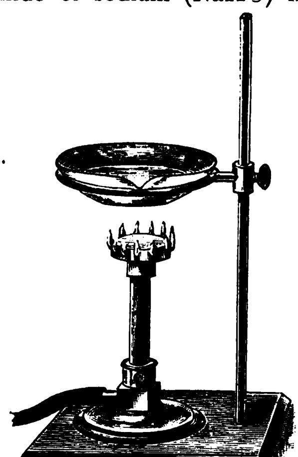


FIG. 106. (*From Newth's "Elementary Practical Chemistry."*)

xperiments show that when ix an acid and an alkali, one destroys the distinguish- operties of the other, so that pound is obtained that has r the properties of an acid ose of an alkali. We say e solution of this compound *tral*, that the acid has neu- d the alkali, or the alkali has lized the acid.

eriment 90.—Obtain a piece of hydroxide or caustic soda. Notice py feel, its caustic or burning on the skin, and then dissolve it r. Dip a red litmus paper in the solution and note the alkaline

reaction. Now add, drop by drop, dilute hydrochloric acid, and s with a glass rod. After every drop or two test solution with red litn paper, and continue adding the acid until the mixture has no action up the red litmus paper. Now test solution with blue litmus paper. If latter is turned red, the solution is acid, and a little more caustic soda solut must be made and added, drop by drop, and the mixture tested after each dr In this way a solution can be obtained which does not affect either red blue litmus. Such a solution is neutral. Evaporate the solution dowr a porcelain dish to a small bulk (Fig. 106), and then divide it into two pa One part evaporate to dryness, when a white crystalline salt will be left, wh on being tasted, will be at once recognized as common salt. Put the ot part into a large watch-glass and allow the water to slowly evaporate, wh by the aid of a lens, the well-known cubical crystals of common salt wil seen. The chemical change that has taken place may be thus represente

NaHO	+	HCl	=	NaCl	+	H_2O
Caustic soda.		Hydrochloric acid.		Common salt.		Water.

Experiment 91.—Repeat the last experiment, using potassium hydro: or caustic potash instead of caustic soda. In this case potassium chlo: will be formed when the alkali is neutralized by hydrochloric acid, thus

KOH	+	HCl	=	KCl	+	H_2O
Caustic potash.		Hydrochloric acid.		Potassium chloride.		Water.

If sulphuric or nitric acid had been used in the last t experiments, the sulphates and nitrates of sodium and potassi would have been obtained on neutralization of the alkal according to the following chemical equations :—

2NaOH	+	H_2SO_4	=	Na_2SO_4	+	$2H_2O$
Caustic soda.		Sulphuric acid.		Sodium sulphate.		Water.
KOH	+	HNO_3	=	KNO_3	+	H_2O
Caustic potash.		Nitric acid.		Potassium nitrate.		Water.

109. **Bases and Salts.**—Alkalies belong to a special c of chemical compounds called *bases*. A base is a compou body capable of neutralizing an acid partly or entirely. Alka are bases that are very soluble in water. Many of metallic oxides are also bases; for they, like the alkalies, poss the power of neutralizing acids. Thus if copper oxide warmed with diluted hydrochloric acid as long as the acid ' dissolve it, the corrosive properties of the acid are destroy and the solution contains a new substance called copper chlori which can be obtained in the solid form by evaporati thus :

CuO	+	2HCl	=	$CuCl_2$	+	H_2O
Copper oxide.		Hydrochloric acid.		Copper chloride.		Water.

In a similar way, by adding zinc oxide (formed by burn

zinc in oxygen) to dilute sulphuric acid, we get a substance called zinc sulphate, formed thus:

$$\underset{\text{Zinc oxide.}}{ZnO} + \underset{\text{Sulphuric acid.}}{H_2SO_4} = \underset{\text{Zinc sulphate.}}{ZnSO_4} + \underset{\text{Water.}}{H_2O}$$

The compound substance thus formed when a base neutralizes an acid is called a *salt*, and a salt may be defined as a compound formed when the hydrogen of an acid is replaced by a metal. As seen from the equations in the last two paragraphs, water is always formed when an acid is neutralized by a base, so that—

$$\text{Base} + \text{Acid} = \text{Salt} + \text{Water.}$$

110. **Iron.**—The element iron is the most useful of metals. It is generally obtained from its ores by smelting. When pure it has a white metallic lustre, and does not suffer any change in dry air or in distilled water. When, however, the metal is left exposed to moist air, or placed in water containing dissolved air, it becomes coated with reddish-brown scales we call *rust*. That when iron rusts it combines with oxygen to form an oxide, and thereby increases in weight, is proved by the two following experiments:—

Experiment 92.—Into a wet gas-jar sprinkle some bright iron filings so that some of them adhere to the sides. Invert the jar into a dish containing some water, and allow the apparatus to stand for a day or two. At the end of the time the filings are bright no longer, but have become "rusty." Look at the water and notice that it has risen inside the jar considerably, in fact about one-fifth of the volume of the jar is now filled with water. Keeping a glass plate over the mouth of the jar, lift it out of the trough and place it upright on a table. Test the gas with a lighted taper. The light is at once extinguished, thus showing that the oxygen has been removed from the air that was in the jar. The gas left is atmospheric nitrogen as in Exper. 78. Rusting, therefore, is a similar process to burning, though the former takes place much more slowly. It is a process of oxidization, and the iron filings should have consequently increased in weight.

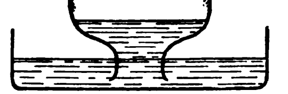


FIG. 107.

Experiment 93.—Weigh out accurately about 10 grains of iron filings in a crucible or capsule. Moisten them with water and dry them rapidly in an oven. Repeat the moistening and drying three or four times, and then

re-weigh. You will find that the filings have become rusty and increased in weight.

111. **Mercury.**—Mercury, or quicksilver, is the only element that is liquid at ordinary temperatures. Its low point ($-39{\cdot}5°$ C.), its high boiling-point ($357°$ C.), specific heat ($0{\cdot}033$), make it specially suitable for the tion of thermometers (par. 64), while its high specific ($13{\cdot}5$) and its property of not wetting glass render it pa suitable for the construction of barometers.

The specific gravity of mercury may be found in way as that of other liquids (par. 19). A small counterpoised, filled with water, and the weight of t found. The bottle is then emptied, filled with quicksi weighed again. The comparative weight or specific g the mercury is thus easily obtained.

Another interesting way of finding the specific g mercury may be now described.

Experiment 94.—Pour some of the liquid into a glass U-tub fill the bend to a little distance on each side. Notice that the colu at the same level in each limb, since water liquids always stand at the same level in f municating vessels. Now pour into one limb of water, and it will be found that it wil upon the mercury as to lower the height in and raise it correspondingly in the other. the height of the column of water LM above of the depressed mercury, and then measure of the mercury column in the other limb level of the mercury in the limb to which was added, PN; LM will be found to be times PN. At L and P on the same level th is the same, therefore a column of mercury o height balances a column of water $13\frac{1}{2}$ time and mercury must, therefore, be $13\frac{1}{2}$ times he water to do this.

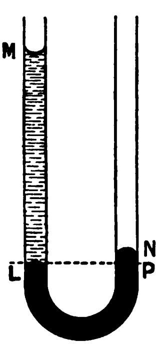


FIG. 108.

Owing to its high specific gravity, a piece of iron, and most other soli on mercury. All the ordinary metals except iron and dissolve in mercury, the metal and the mercury uniting peculiar substances termed "amalgams." Zinc plates voltaic cells are rubbed with mercury, which adhere surface. They are then said to be "amalgamated,"

is done to protect the plates from corrosion by the acid when the battery is not in use. Looking-glasses are "silvered" with an amalgam of mercury and tin.

Mercury gives off vapour very slowly at ordinary temperatures, but on heating in a test-tube it is readily volatilized. Some of the vapour will condense on the cool part of the tube as a bright metallic ring.

When mercury is exposed to a high temperature in contact with air for several days, a red oxide is formed on the surface. This red oxide, if strongly heated, is split up again into oxygen and metallic mercury.

$$\underset{\text{Mercuric Oxide.}}{HgO} = \underset{\text{Mercury.}}{Hg} + \underset{\text{Oxygen.}}{O}$$

The experiment may be performed, and the oxygen gas collected, by using the apparatus shown in Fig. 104.

112. **Silica or Silicon Dioxide (SiO_2).**—Silica is the only known oxide of silicon, and is the most abundant binary compound found in the earth's crust. It is found in nature in a variety of forms, of which quartz, sand, flint, and agate may be taken as examples.

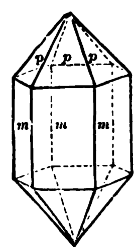


FIG. 109.—Form taken by quartz crystal: *p*, pyramid planes; *m*, prism planes.

Quartz is a common crystalline form of silica, the crystals being in the form of hexagonal prisms, bounded at the ends by hexagonal pyramids. Complete crystals, with both ends perfect and all the faces equally developed, are rare. A cluster of them may often be found springing from a common base and having the free ends of the prisms terminated by pyramids (Fig. 109). The angle between adjacent faces of a crystal always forms 120°. Quartz is so hard that it will scratch glass, and a knife will not scratch it. A pure transparent kind of quartz is known as *rock-crystal*, and is used under the name of Brazilian pebble to form lenses for spectacles.

Sand is largely composed of grains of quartz that have been worn more or less round by rubbing. Sandstone has been formed by the grains becoming united under great pressure by some cementing substance.

Flint and *Agate* are non-crystalline or amorphous varieties of silica. Flint is a dark-coloured impure variety of silica that is found occurring in nodules and sheets. The nodules can be broken into fragments with sharp cutting edges, and such fragments were formerly used with a piece of steel for obtaining fire. Agate is an extremely hard variety of silica, formed of layers having different colours. It is used for making ornaments, and also for making mortars in which substances are pounded.

Opal is an amorphous variety of silica containing water. It often shows a beautiful play of colours, and is much used for ornaments.

All the forms of silica are quite insoluble in water, and also in all acids except hydrofluoric acid. The amorphous variety, however, is somewhat soluble in alkaline solutions. This may be shown by trying the action of water and the common acids on the varieties of silica mentioned above.

Silica united with the oxides of other metals forms compounds called *silicates*. Many rocks, as will be shortly learnt, are largely composed of silicates. Most silicates are very insoluble substances, but the silicates of sodium and potassium are soluble, and are often spoken of as *soluble glass*.

Experiment 95.—Obtain some soluble glass composed of sodium silicate. Note its glassy appearance when broken. Powder a portion and boil it with a little water. A viscous alkaline solution will thus be obtained. To this add strong hydrochloric acid, when a gelatinous mass of silica separates out.

CHAPTER XII.

THE MINERALS OF THE EARTH'S CRUST.

113. **The Crust of the Earth.**—The term "crust of the earth" is used to denote the exterior portion of the earth that can be observed and examined, that is, the "upper or outer layers of the earth's mass." We have no means of knowing what is now the real structure and condition of the earth's interior; but by inspecting quarries, railway cuttings, sea cliffs, ravines, wells, mines, and the material sent out by volcanoes, we can learn something about the outer parts of the solid earth, and it is to this outer portion that we refer when we speak of the "crust." The total thickness of the earth's crust penetrated by man is only a few thousand feet, and the highest mountains are not more than 30,000 feet high. Although our reasoning may lead us to infer something about the rocks to a depth of nearly fifty miles, yet, considering that the centre of the earth is nearly 4000 miles from the surface, we have only knowledge of but a small fraction of the earth's radius.

114. **Rocks and Minerals.**—Every one has noticed that the solid parts of the earth consist of distinct substances, such as clay, limestone, chalk, sand, coal, peat, granite, etc.; and to these several substances which form the materials of the earth's crust we give the name *rock.* Some are hard and firm, others are soft and loose; but all alike are called rocks. Hence we see that while in ordinary language the word "rock" denotes a great mass of hard stone, in geology *a rock is any mass of natural substance forming part of the earth's crust.* In this sense, loose sand, gravel, and soft clay are as much rocks as hard limestone and granite.

Rocks are formed of various materials called *minerals.* If we take a piece of sandstone rock, or a piece of granite, we shall probably be able to notice that the rock is made up of different substances.

Obtain and examine a specimen of coarse-grained *sandstone.* On looking at it carefully, especially if we use a magnifying-glass, we see that it is composed of little rounded grains of a glassy-looking substance cemented together. In some specimens these grains are larger than in others. This cementing material is not the same in all sandstones, but in

our specimen it is formed of calcium carbonate, for when we drop a little dilute hydrochloric acid on the rock there is an effervescence of a gas (carbon dioxide) and the cementing material is dissolved. But the little rounded grains, which consist of quartz, are not affected by the acid. Sandstone, then, consists of quartz grains cemented together by calcium carbonate or some other cementing substance. In some sandstones the cementing material and the grains themselves are coloured yellow or brown by rust (oxide of iron).

Now take a piece of *granite*, and break it with a hammer to get a clean-cut face. On looking at this face we see that the rock is made up of three different substances.

One of these has a glassy appearance like the grains in the sandstone, and is so hard that we cannot scratch it with a knife. This is *quartz*. Another of the substances is of a dull white or pinkish colour. It lies in long smooth-faced crystalline patches, which easily break along a number of smooth parallel surfaces having a pearly lustre. It can be scratched with difficulty by the point of a knife. This substance is called *felspar*. The third substance consists of bright glistening plates, sometimes of a dark colour, which can be easily scratched, and which readily split into transparent leaves. This is *mica* (Lat. *mico*, to glisten). Notice that these substances do not occur in any definite order, but are scattered about through the stone irregularly, the felspar occurring in some specimens in larger crystals than in others.

FIG. 110.—Piece of granite (crystals of felspar light, of mica black).

Hence we see that granite consists of a mixture of three substances, called quartz, felspar, and mica, the felspar being in greatest quantity. Each of these substances possesses properties more or less peculiar to itself, such as hardness, solubility in acids, specific gravity, crystalline form, way of splitting, etc. Moreover, each of these substances has a constant chemical composition.

Thus quartz is a binary compound known in chemistry as silica, and a molecule always consists of one atom of silicon united to two atoms of oxygen (SiO_2). The calcium carbonate is represented by the formula $CaCO_3$. It is a ternary compound, formed of the three elements calcium, carbon, and oxygen, chemically united. It may also be regarded as formed of the two oxides, CaO, calcium oxide or quick-lime; and CO_2, carbon dioxide (CaO,CO_2).

The felspar of the granite contains four elements. Its formula may be thus represented: $Al_2O_3,K_2O,6SiO_2$. This shows it to be made up of three oxides, Al_2O_3, alumina; K_2O, potash; SiO_2, silica, that is, it is a silicate of alumina and potash.

115. **Minerals.**—Inorganic bodies which have a definite

chemical composition and constant physical properties, are called minerals; and rocks are formed either of one mineral, or more generally of a mechanical mixture of minerals. Hence we give the following definition of a mineral:—*A mineral is a naturally formed inorganic substance which has a constant chemical composition and constant physical properties.* This definition may be understood to include such substances as coal and chalk, which are the mineralized remains of plants and animals respectively. Even water and the gases of the atmosphere may be said to belong to the mineral kingdom of nature, as plants and their parts are said to belong to the vegetable kingdom, and animals and their parts to the animal kingdom.

116. **Chief Rock-forming Minerals.**—The total number of rock-forming minerals is large, but many of them are rare and form but a small part of the earth's crust. The following table gives the percentage by weight of the most important minerals:—

The Percentage of Minerals in the Earth's Crust.

1. Felspar	48	6. Amphibole (hornblende)	1
2. Quartz	35	7. Pyroxene (augite)	
3. Mica	8	8. Diallage	
4. Talc	5	9. Peridot (olivine)	
5. Carbonates of lime and magnesia	1	10. Clay (in all its forms)	1
11. Other substances	1		

Though felspar is found to be the most abundant mineral, it is worthy of note that *silica* (SiO_2) is the most abundant *compound*, for it not only occurs separately as quartz to form 35 per cent. of the earth's crust, but it occurs in combination with other oxides to form felspar, mica, and talc.

Analysis of the minerals shows the chemical elements entering into their composition, and from this a calculation has been made of the proportion by weight of the *elements* present in the outer layers of the earth.

Percentage of Elements in the Earth's Crust.

1. Oxygen	50·0	7. Potassium	1·6
2. Silicon	25·0	8. Carbon	2·4
3. Aluminium	10·0	9. Iron	
4. Calcium	4·5	10. Sulphur	
5. Magnesium	3·5	11. Chlorine	
6. *Sodium*	2·0	12. Other bodies	1·0

Oxygen is, therefore, the most abundant element entering into the composition of the earth's solid crust, and silicon is next. Neither of these, however, is free or uncombined. For the most part the two are combined to form silica.

Oxygen also, in combination with hydrogen, forms eight-ninths of water by weight (par. 99). It also forms about one-fifth by weight of the atmosphere, and in the atmosphere it is in the free state (par. 100).

We will proceed to describe a few of the chief rock-forming minerals, after pointing out the various properties that are most useful in identifying minerals.

117. **Identification of Minerals.**—Minerals can be identified and distinguished by various physical properties and by ascertaining their chemical composition. The chief distinguishing physical properties are *crystalline* form, *cleavage*, *hardness*, and *specific gravity*.

Each mineral or special class of minerals has its own definite geometrical shape or crystalline form. The crystals of each mineral have also a tendency to break or cleave most readily in a particular direction. The term *hardness*, as applied to minerals and other solid bodies, is used to indicate resistance to being scratched or the power to scratch. The harder of two bodies is the one which will scratch the other, and which resists being scratched by that other.

To find the relative hardness of substances, a scale has been arranged, beginning with the softest mineral (talc) and ending with the hardest (diamond). The minerals of the scale, therefore, are so arranged that each will scratch any other mineral of lower number in the scale, or be scratched by any of higher number.

38. *Scale of Hardness.*

Mineral.		Chemical name.
1. Talc.	Can be scratched by the finger-nail.	1. Magnesium silicate.
2. Gypsum (or rock-salt).		2. Calcium sulphate or Sodium chloride.
3. Calc-spar.	Can be scratched by knife or file.	3. Calcium carbonate.
4. Fluor-spar.		4. Calcium fluoride.
5. Apatite.		5. Calcium phosphate.
6. Felspar.		6. Potassium and aluminium silicates.

Mineral.		Chemical name.
7. Quartz (rock-crystal).	Cannot be scratched by knife or file.	7. Silica.
8. Topaz.		8. Aluminium fluosilicate.
9. Corundum (sapphire, ruby).		9. These gems are crystallized alumina.
10. Diamond.		10. Crystallized carbon.

The important property of specific gravity has already been described and the method of finding it explained (par. 22).

As a first inquiry into the chemical composition of a mineral, dilute hydrochloric or sulphuric acid is tried. All carbonates effervesce when placed in acid or when acid is dropped upon them, while quartz and all the silicates show no effervescence when so treated.

118. **Felspar.**—Felspar is the name given to a class of minerals consisting of silicate of alumina combined with one or more other silicates—silicate of potash, soda, lime or magnesia. The two chief kinds of felspar are known as *orthoclase* (straight-cleaving) and *plagioclase* (oblique-cleaving). Orthoclase felspar is a potash felspar, that is, it consists of silicate of alumina and silicate of potash. It crystallizes in oblique rhombic prisms (Fig. 111) and shows two cleavages at right angles. Its colour varies from white to pink; it has a glassy lustre; and its hardness is about 6. Orthoclase forms the most conspicuous mineral in many granites. Plagioclase felspar is a soda or lime felspar, that is, it consists of silicate of alumina and silicate of soda or lime. It crystallizes in rhomboidal prisms, and shows two cleavages not exactly at right angles. The specific gravity of the felspars varies from 2·6 to 2·8. The decomposition of felspar gives rise to clay. *Kaolin*, or china clay, is simply hydrated silicate of alumina derived from the weathering of felspar.

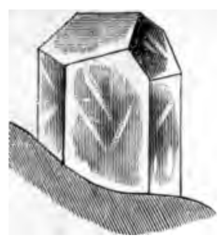


FIG. 111.—Crystal of felspar.

119. **Quartz.**—As already mentioned, the mineral quartz consists of silica or silicon dioxide alone. A crystal of quartz when complete is made up of a six-sided prism, terminated at each end by a six-sided pyramid (Figs. 109, 112). Perfect crystals are rare. One pyramid is often wanting, while some of the faces are more strongly developed than others. But the angles formed by the meeting of the faces are always of exactly the same size for the same kind of mineral.

Quartz crystals are sometimes clear and transparent, sometimes mi white, sometimes purple (amethyst), sometimes yellow (cairngorm), a sometimes brownish (smoky quartz). Quartz is also found massive, without definite crystalline shape, and amorphous or entirely non-crystalli Broken quartz crystals are common in sandstone and other sediment rocks.

Crystals of quartz show no definite cleavage, are hard enough to scrat

FIG. 112.—Crystals of quartz (rock-crystal). The lines on the crystals only indicate shading.

glass or steel (7 on the scale), and have a specific gravity of about 2 Quartz is also unaffected by all the common acids.

120. **Mica.**—Mica is a mineral that consists of silicate of alumina co bined with silicate of potash or magnesia, and t crystallizes in six-sided columns (Fig. 113, where crystal rests on one of the six faces of the colum The potash micas are white and the chief is cal *muscovite* mica; the magnesia micas are black, the chief is called *biotite* mica. They all hav pearly lustre, and the six-sided crystal columns rea cleave into six-sided glittering flexible plates. hardness of mica is between 2 and 3, and its spec gravity varies from 2·8 to 3. Broken shining fla of mica are readily seen in granite, loose sand, in many sandstones.

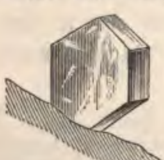


FIG. 113.—Crystal of mica.

121. **Hornblende** and **Augite** are minerals consisting of silicate of magnesia with silicate of lime and oxide of iron. Some varieties also contain alumina. They are common in certain igneous rocks.

The mineral *olivine* is a ferro-magnesian silicate, and *serpentine* is the same with the elements of water.

Talc is a hydrated silicate of magnesia of light colour and very soft (1 on the scale). It is unctuous to the touch, so that the massive variety is called Steatite or Soapstone.

122. **Calcite.**—Calcite is the name given to an abundant mineral formed of calcium carbonate ($CaCO_3$). It is from this mineral that lime (CaO) is obtained when the carbon dioxide is driven off by heat (par. 105). So that rocks consisting of any form of calcite are often spoken of as calcareous rocks (Lat. *calx, calcis*, lime).

Several important varieties of calcite are found. Iceland spar, dog-tooth spar, marble, and limestone are common varieties of calcite.

Iceland spar is a transparent crystalline variety of calcite, the crystals forming rhombohedrons and exhibiting the curious optical property of double refraction. The rhombohedron is a solid bounded by six faces arranged in three parallel pairs, each of the faces being a rhombus (Fig. 114). Rhombohedral calcite readily cleaves into smaller and smaller similar rhombohedrons. Its hardness is 3, and its specific gravity 2·7.

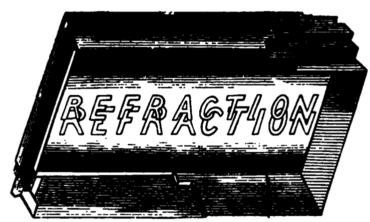


Fig. 114.—Rhombohedral crystal of Iceland spar showing double refraction.

In *dog-tooth spar* the rhombohedral crystals of calcite terminate in pointed pyramids. *Marble* is a massive variety of calcite, though a special kind of marble used for statues shows small granular crystals matted together. *Limestone* is a general name used for all kinds of uncrystallized calcium carbonate.

All kinds of calcite are easily scratched with a knife, and effervesce readily when a common acid is dropped upon them.

123. **Dolomite.**—Dolomite is a mineral formed of two carbonates—calcium carbonate and magnesium carbonate—united together. It forms rhombohedra when crystallized, has a brownish colour, is a little harder than calcite, and does not effervesce so easily with an acid.

124. **Gypsum.**—Gypsum is a mineral formed of hydrate calcium sulphate ($CaSO_4 + H_2O$). It occurs in arrow-headed crystals, in a semi-transparent pearly form (*selenite*), and in opaque masses called *alabaster*. It scratches easily (hardness 2), but does not effervesce with an acid. When burnt, gypsum loses its water, and an opaque white powder called plaster of Paris is left.

125. **Rock-salt** is a mineral consisting of sodium chloride (NaCl). It occurs in beds of considerable thickness, a bed of gypsum often separating two beds of rock-salt. When quite pure it is colourless, but it is often coloured by impurities. It crystallizes in cubes.

126. **Ores** are minerals from which useful metals may be extracted. Thus tinstone, or oxide of tin (SnO_2), galena, or sulphide of lead (PbS), and red hematite, or ferric oxide (Fe_2O_3), are ores. The metallic ores occur scattered through other rocks, chiefly in narrow veins or threads, called *metallic veins*.

Some metals are found free, that is, uncombined with any other elemen and they are then said to be *native*. Gold, silver, platinum, and coppe are found native.

127. We now pass on from the rock-forming minerals to learn something about the rocks themselves. Before doing so, we will ask the student to remember the definition of *mineral* and of *rock*. He will not then be confused by asking whether a given specimen is a mineral or a rock. It may be both, for all rocks are formed of one or more minerals. Thus rock-salt or dolomite are minerals when we are considering their chemical and physical properties; they are rocks when we consider that they occur in beds in the earth's crust.

CHAPTER XIII.

THE CLASSIFICATION AND DESCRIPTION OF ROCKS.

128. **Stratified and Unstratified Rocks.**—According to their origin and mode of formation, rocks are divided into two great classes—stratified and unstratified.

On looking at a sea-cliff, a deep railway cutting, or a quarry, we are often able to notice that beneath the soil the rocks are arranged in more or less parallel layers, either horizontal or inclined. Such layers are called strata, and the rocks *stratified*

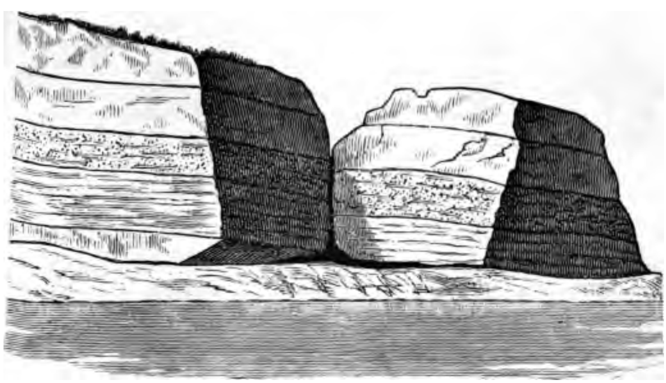


FIG. 115.—Stratified rocks.

rocks (Lat. *stratum*, pl. *strata*, what is spread out). In Fig. 115 five layers or strata may be seen. Sandstone, limestone, chalk, clay, shale, etc., belong to the stratified rocks.

In other cases no traces of layers or beds can be detected, for the rock merely forms a great mass of mineral matter, with a massive lumpy appearance; such rocks are called *unstratified*. *Granite and basalt* are unstratified rocks.

There is every reason to believe that the stratified rocks have been subject to the action of water, for they show indications of either having been mechanically suspended in it, or chemically dissolved in it. Hence the stratified rocks are also called *aqueous rocks* (Lat. *aqua*, water). We believe that the beds or strata have been spread out by the action of water owing to the many signs of water-action that they still retain, and also because we can observe at the present time that, whenever a running stream has its velocity checked on entering a lake or the sea, the pebbles, sand, or mud that it brings down are spread out in horizontal layers on the bottom. But the stratified rocks do not always preserve this horizontal arrangement, for they have often undergone displacement and upheaval after their original deposition.

The unstratified rocks show many signs of having been subject to the action of intense heat, some of them having

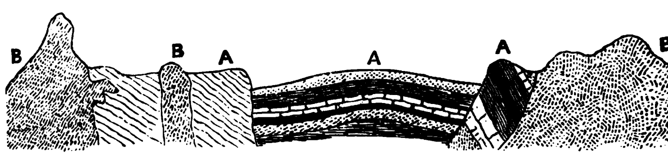


FIG. 116.—A, stratified rocks; B, unstratified rocks.

evidently been in a molten state, the minerals of which they are composed showing a crystalline structure. Hence they are also called *igneous* (Lat. *ignis*, fire). These rocks are generally found in mountainous districts, and have often been pushed up from below through the overlying strata. In one place they rise up as huge conical hills, in another they may be seen filling up rents and fissures like walls or dykes, while in another district they have spread out on the surface in streams of lava.

It is from the broken-down or disintegrated materials of the igneous rocks that the stratified rocks have been formed in the first instance. Thus by the decomposition of the felspar in granite, clay is produced, and most sand-grains have been derived from the quartz of the same rock. These sand-grains

become consolidated into sandstone, and this in its turn may be broken up again, to again undergo further consolidation.

We will now put the differences between these two great classes of rocks into the form of a table.

Stratified or aqueous rocks.	Unstratified or igneous rocks.
1. Possess evident marks of bedding.	1. Possess no true marks of bedding.
2. Are derived from previously existing rocks.	2. Are the oldest and primitive rocks.
3. Are situated usually in plains and on the flanks of mountains.	3. Are situated in mountainous districts, and often compose the axis or nucleus of a mountain chain, sometimes filling up long upright fissures, and forming vertical masses called *dykes*.
4. Are formed of minerals which have usually a non-crystalline structure.	4. Are formed of minerals usually having a crystalline structure.
5. Have plainly been deposited one after another from above.	5. Have been erupted or driven out from the interior.
6. Contain the remains or impressions of plants and animals that existed at the time the rocks were deposited. These remains or marks are called fossils, and hence such rocks are called *fossiliferous*.	6. Contain no organic remains except such as were buried in volcanic ashes or mud during an eruption. Hence called *unfossiliferous*.

129. **Metamorphic Rocks.**—Besides the stratified and unstratified rocks, there is another class of rocks which, though originally stratified, in most cases have undergone great alterations in structure and composition, whilst traces of fossil remains have been destroyed. These are called metamorphic or transformed rocks (Gr. *meta*, change; *morphê*, form).

To this class belong clay-slate, quartzite, statuary marble, mica-schist, and gneiss, which will presently be described.

The chief agents concerned in these changes are heat, water, and pressure. Metamorphic rocks are chiefly found next to intrusive igneous rocks; and it is probably owing to the heated state of these that many of the stratified rocks that adjoin them have been metamorphosed or transformed.

130. **Crystalline and Non-Crystalline Rocks.**—The above twofold division of rocks, based on the mode of their formation into (*a*) unstratified or igneous, and (*b*) stratified or aqueous, corresponds closely to another twofold division, which is based on the *texture* of the rocks, that is, on the arrangement of the particles forming any given rock. As a rule we find that the igneous rocks have a crystalline texture, while the stratified rocks are non-crystalline. But to this general statement there are some exceptions. In speaking of crystallization we saw that substances assume those definite geometrical shapes called crystals when they have either been in solution in a liquid or in a molten condition through heat. When in either of these states we know that the particles of many substances have the power of taking up definite positions round a centre as the liquid evaporates or as the fused mass cools, and the crystals are formed by the successive addition of particles to the exterior, large crystals being built up by the regular addition of a number of small crystals. As the igneous rocks are believed to have been at one time in a state of fusion, we find that they usually consist of a network of interlaced crystals and crystalline particles, the crystals being often large enough to be visible to the naked eye, as in granite. In other cases we need to make a very thin section of the rock and examine it under a microscope to see the crystalline texture; while in the case of a few igneous rocks, such as some lavas, where cooling has taken place rapidly, the rock only shows a glassy or vitreous structure, as in obsidian (volcanic glass). But as these glassy or vitreous rocks often show under the microscope incipient forms or beginnings of crystals, called microliths, or crystallites, in the glassy base, it is usual to include such rocks in the crystalline class. On the other hand, the ashes and other fragmentary materials sent out from volcanoes may be called non-crystalline or fragmental igneous rocks.

The aqueous or stratified rocks, being in all cases formed of materials derived from pre-existing rocks, are usually composed of particles having no definite arrangement and showing no crystalline structure. These fragments out of which the stratified rocks have been formed are of various sizes, from blocks of several feet to exceedingly fine powder, and have been generally massed together irregularly by mechanical compression or the infiltration of some cementing substance. The names given to these various fragmental or non-crystalline rocks, and the mode in which the particles have been bound together into masses, will be explained presently. But where the material from which an aqueous rock has been formed has been in solution in water, the deposit from this aqueous solution possesses a crystalline texture, as in some limestones formed from precipitated calcium carbonate. Beds of gypsum (calcium sulphate) and rock-salt are other examples of crystalline aqueous rocks.

The metamorphic rocks, being stratified rocks that have been changed by the action of heat and heated water, also show a crystalline texture. One peculiarity of this class of rocks, viz. the arrangement of the crystalline minerals forming them into layers so as to give them a foliated appearance, will shortly be noticed (see Gneiss, par. 141).

Putting the above in a tabular form, we may set it forth as below:—

Crystalline	Igneous—granite, basalt, etc. Aqueous—some limestones, gypsum, rock-salt. Metamorphic—gneiss, statuary marble.
Non-crystalline or fragmental	Igneous—volcanic ash. Aqueous—sandstone, clay, conglomerate, shale, coal, etc.

131. **The Aqueous or Stratified Rocks.**—The great class of stratified rocks may be divided into three smaller divisions. These divisions, with the chief rocks of each division, may be tabulated as follows :—

(*a*) Mechanically formed rocks from detrital sediments	Conglomerates, sandstones, clay, and shale.
(*b*) Organically formed rocks from animal and plant remains	Limestones, chalk, coral, peat, and coal.
(*c*) Chemically formed rocks from material once in solution	Limestones, stalactites, gypsum, rock-salt, and sinter.

132. (*a*) **The Mechanically formed Stratified Rocks.**—These rocks consist of pieces, large or small, broken from other rocks and then consolidated into masses. They are, therefore, all *derivative*, *i.e.* formed from pre-existing rocks. Streams, rain, and waves are continually wearing away portions of the earth's crust and carrying it down to be deposited at a lower level where the water comes to rest. This mechanically suspended matter in the water is often called *sediment*, and it is easy to understand that the larger and heavier particles of the sediment will be the first to be deposited, the finer ones being carried further. Part of this sediment may consist of small rounded pebbles called gravel, part of sand, and part of very fine particles called clay or mud. Sedimentary rocks are those which have been formed out of sediments on the floors of lakes, in river-beds, or on the sea-bottom, and have afterwards been raised above the surface. In process of time the materials are made to cohere by pressure and the infiltration of cementing substances.


Fig. 117.—Conglomerates.

These different kinds of sediment give rise to different sorts of sedimentary rocks—*conglomerate*, *sandstone*, and *clay*.

Conglomerate, or puddingstone, as it is called sometimes, consists of rounded water-worn pebbles, or masses of various rocks cemented together by some kind of mineral paste. This cementing material may be formed of carbonate of lime, silica, or oxide of iron. It is brought in solution by water, and as the water evaporates is deposited among the pebbles as a cement.

The pebbles forming a natural conglomerate may be derived from any kind of rock. If the pebbles are composed of quartz, or flint, we may call it a silicious conglomerate; if of limestone, a calcareous conglomerate. When the rock-fragments that are cemented together have sharp angular corners, showing that they have not been subject to much water-action, the rock is called a *breccia*.

Sandstone.—This rock has already been described (par. 114). The rounded water-worn grains of sand, which have been derived from the breaking up of rocks containing quartz, sometimes lie separate, and form large beds of loose sand. This loose sand consists mostly of silicious grains, sometimes with small particles of mica and fragments of shells.

On some sandy coasts, as the tides run down, the sand is left dry, and being caught up by the wind is blown inland, so that in the course of years a ridge of hills, called *sand-dunes*, is formed. When the loose sand is, however, left undisturbed at the bottom of the sea or of a lake, in process of time it becomes consolidated by pressure and by cementing material. This cementing material varies as in the case of conglomerate, and hence we have *calcareous* sandstones and *ferruginous* (Lat. *ferrum*, iron), according as the cementing material is calcium carbonate or oxide of iron. The oxide of iron usually colours the sandstone yellow or red. Sandstone is much used for building purposes, often forming window-sills, lintels, and doorposts. Some kinds show a tendency to split into slabs parallel to the stratification, and are then much used for flagstones. When the silicious particles are rather large and angular the sandstone is called a *gritstone*. Such gritstones are often used for grindstones and millstones.

Sandstones are spoken of as arenaceous rocks (Lat. *arena*, sand).

Clay consists of very fine sedimentary particles that adhere together and form a substance that can be easily moulded into various shapes. Hence it is said to be plastic. It is the last result of the waste of rocks by water and other natural agents. It is chiefly composed of silicate of alumina with water ($Al_2O_3,2SiO_2,2H_2O$). It is derived mainly from the decomposition of felspar and other aluminous silicates by the action of the weather, the potash and the soda being washed away, especially by water containing carbonic acid in solution. It is generally found in valleys and lowlands, and has the important property of being impervious to water. Hence where there is a series of beds of porous rocks, such as sand, gravel, or chalk, resting on clay, the water sinks through these until it reaches the clay. It then accumulates until it can find an outlet, for clay is an impermeable rock (par. 230). Clay is often mixed with various impurities, which impart to it a brown, red, or blue colour. Kaolin, or china clay, is the name given to a pure kind much used for the manufacture of porcelain. Common clay is much used for making bricks.

Rocks containing much clay are called *argillaceous* (Lat. *argilla*, clay).

When mixed with water, clay forms *mud*, though the word "mud" is applied to any finely divided mineral matter.

Shale is clay or mud that has become hardened, and which splits into thin plates or laminæ, parallel to the stratification. Such rocks are said to be laminated, and thus show that they have been gradually deposited under water.

Shales are often dark-coloured through vegetable matter, and frequently have the impression of ferns, etc., distinctly marked. All clayey rocks give out an earthy smell when breathed upon.

133. (*b*) The Organically formed Stratified Rocks.—This

division of the aqueous rocks consists of the remains of once living organisms, that is, the remains of animals and plants, that have become mineralized and hardened. The organic rocks include the various kinds of limestone, coral, coal, peat, and silicious rock, termed sinter.

Limestone is a name often used to include all rocks that consist of calcium carbonate ($CaCO_3$). The limestones that are of organic origin include *chalk*, *encrinital limestone*, *oolite*, and *coral*.

Chalk is a white soft limestone consisting largely of the

FIG. 118.—Various forms of foraminifera, highly magnified.

minute shells of *foraminifera*. Foraminifera are minute specks of living jelly-like protoplasm that possess the power of secreting calcium carbonate from sea-water, and of forming with it beautiful microscopic many-chambered cells. The protoplasm occupies the interior of the shell and sends out thread-like processes through apertures (Lat. *foramina*, holes) in the shell (Fig. 118, *c*).

Globigerinæ are a very common kind of foraminifera. On rubbing soft natural chalk with a brush and allowing the finer particles to be washed away, tiny shells and fragments of shells

of various shapes may be seen under the microscope. In a thin section of the harder variety similar shells may be seen, most of them belonging to the foraminifera.

We shall afterwards learn that foraminifera still live in countless millions in the sea and form their tiny shells so that a white chalky deposit called globigerina ooze is now being deposited on the ocean floor (par. 197).

An interesting point connected with beds of chalk is the fact that nodules of flint (silica) are often found in great numbers among the chalk. The origin of these flint nodules is interesting, for the silica of which they are made appears to have been in solution in sea-water containing gas in solution. This dissolved silica, partly derived from sponge spicules, has then been deposited around some nucleus, and the masses so formed have fallen down among the chalk, producing ooze.

There is a variety of organic limestone called *encrinital limestone*, since it is largely composed of the calcareous joints of small marine animals, termed sea-lilies or encrinites, which attach themselves by means of a jointed stem. This limestone, after being exposed to weather action, often show parts of these jointed stems very clearly. Polishing the stone also brings out its structure.

FIG. 119.—Limestone showing stems of encrinites.

Another kind of limestone common in some parts of England is called *oolitic limestone*, or *oolite*, or *roe-stone* (Gr. *oon*, an egg). It is so-called because it consists of small rounded calcareous grains cemented together.

134. **Coral** is an important variety of limestone that has an organic origin, for the calcium carbonate of which it consists has been secreted from sea-water by certain small gelatinous animals that belong to the class called actinozoa (rayed animals). This particular kind of actinozoa is called the *coral polyp*. Its body is only a mass of soft jelly, with numerous feelers or tentacles at the upper part; but it has the power of attaching itself to submerged rocks in the sea, and of depositing near the outer and lower part of its body a hard mass of calcium carbonate drawn from the sea in which it lives. It thus becomes fixed, goes on increasing in height and breadth, multiplying in various ways, as by budding and splitting, each division growing into a perfect polyp, which adds to the mass of hard substance deposited. In this way are formed pieces

of coral of considerable size and of varying shapes. When the coral polyp dies the soft parts of its body decay and are washed away, but the hard skeleton remains behind, and

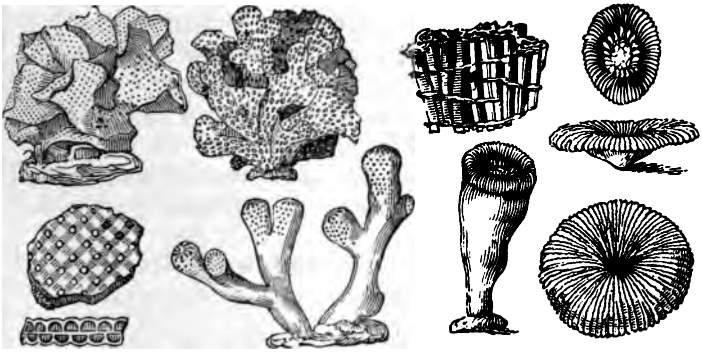


FIG. 120.—Stone corals.

accumulates on the floor of the sea to form masses of land—coral reefs and coral islands.

It must not be supposed that the coral rock is the result of "work" on the part of the coral polyps, in the sense that a bird works when it builds its nest. The secretion of calcium carbonate from the sea-water is as much an unconscious process as is the extraction from food of the mineral matter that forms our bones; and the coral land accumulates by the animals dying below, while new animals grow above. There are two classes of the coral polyps—*detached corals*, living in nearly all seas at any depth; and *reef-building corals*, which can live only in clear water within a limit of 20 fathoms from the surface and where the water is above 68° F. Hence coral rocks are only found in warm waters of the tropical seas. There are many kinds of the coral polyps, and the coral rock is of various forms. Some are shaped like the

FIG. 121.—Small piece of coral, magnified, showing the extended tentacles of the coral polyps.

branches of trees, others resemble tufts of clustered leaves, some form roundish masses, while still others are like groups of coloured twigs. When the animals are living their branching feelers are seen expanded in a great variety of colour and form.

Coral rocks are found as ridges or banks in the sea, and are therefore called coral *reefs*. Coral reefs are divided into three classes :—

(1) *Fringing reefs*, which form a ridge of rock at a short distance from some mainland or island.

(2) *Barrier reefs*, which are banks running nearly parallel to the coast at a greater distance than fringing reefs, so as to leave a broad channel.

(3) *Atolls*, which are ring-shaped belts of coral reef, enclosing a lagoon of shallow water, and forming an island.

It has already been stated that the reef-building corals require for their existence clear water not below 68° F. of temperature, so that where the water is muddy, as near the mouths of large rivers, or where cold currents

FIG. 122.—Rocky island bordered by coral reefs (after Dana). *f*, fringing reef; *b*, barrier reef; *h*, *h*, openings in the reef.

or other causes bring the water below the above temperature, there the reef-building polyps cannot exist. Nor can they exist but in shallow water, for they seem to die at a greater depth than 100 feet. They flourish best where the water is in constant motion and where it is clear, as at the outer edge of the reef. Hence the range of coral reefs and islands is limited by these conditions to a district about 25° on each side of the equator. The Bermuda Islands, which lie in the course of the Gulf Stream, form the northernmost point at which reef-building corals are found, but the Atlantic Ocean has not many of these rocks. Some are found among the West Indies and Cape Verde Islands, and off the coast of Florida. In the Pacific there is a belt of coral rocks, both islands and reefs, stretching from the Low Archipelago to the Caroline Islands. There is also in the Indian Ocean a band of coral islands between Madagascar and India, including the Maldive Islands and the Laccadive Islands. Numerous reefs also occur in the Red Sea (see map II.). The largest barrier reefs are those off the island of New Caledonia and off the north-east coast of Australia.

The Australian barrier reef is nearly 1200 miles long, and usually about 120 miles from the shore. At its outer edge it rises out of the sea from a depth of 1800 feet.

135. **Coal.**—Plants consist of carbon, hydrogen, oxygen, and nitrogen in various combinations. After vegetable matter has been buried in the earth it suffers decomposition, gives off various gases, such as carburetted hydrogen (CH_4) (called also marsh-gas, and by colliers fire-damp), carbonic acid, and water, so that the residue becomes richer and richer in carbon.

By compression and alteration they change into peat, lignite, coal, and anthracite. The following table from Roscoe and Schorlemmer's "Chemistry," which gives the percentage composition of these substances, shows that the elements which make up woody fibre are the same as those which make up coal; and as we pass from wood up to the kind of coal called anthracite we see how the percentage of carbon increases, and how great a decrease there is in the percentage of O and N.

There is also a slight decrease in the percentage of hydrogen.

	Carbon.	Hydrogen.	Oxygen and nitrogen.
Wood	50·00	6·00	44·00
Irish peat	60·02	5·88	34·10
Lignite from Cologne	66·96	5·25	27·76
Earthy coal from Dax	74·20	5·89	19·90
Cannel coal from Wigan	85·81	5·85	8·34
Newcastle Hartley	88·42	5·61	5·97
Welsh anthracite	94·05	3·38	2·57

The vegetable nature of peat is plain from its chemical composition, from its fibrous appearance, and from its being found in boggy places where marshy plants grow and decay. That coal also is of vegetable occurrence is proved by its chemical composition, by the fact that peat under very great pressure is changed into a black shining material resembling coal, by the numerous fossil plants found in coal, and by the fact that when a thin slice is examined under the microscope vegetable tissues and cells are distinctly visible. *Lignite* is a brown coal formed of woody matter mineralized to a less extent than ordinary coal.

When peat and coal are burnt they pass off as gases, leaving a small quantity of incombustible mineral matter behind, which we call ash.

136. **Peat** consists of a brownish-black compressed mass of partially decomposed vegetable matter. It is found in many marshy and boggy districts. At the surface of a *peat bog* there grows a green living moss, called "bog-moss," with other marsh-loving plants. A few inches below are found the brown, rotting fibres of the dead moss, and still further, the mass becomes denser and darker. Still deeper, 8 or 10 yards deep, we often find a compact blackish substance which can be cut into blocks. These blocks are piled in stacks, allowed to dry, and used for fuel.

Coal and peat are both of vegetable origin, but they differ in chemical composition (peat having a less percentage of carbon and a greater percentage of oxygen and hydrogen), in density (peat being less dense than coal), in the kind of plants out of which each has been formed, and in their mode of occurrence. Coal is found buried in the crust of the earth in *beds* or *seams*, varying in thickness from a few inches to several yards. As it is arranged in layers, and as by examining a large piece we can find one particular direction in which it will split most easily, it is plain that coal is a stratified rock. Every bed of coal is found to rest upon a bed of clay, usually hardened into shale, and this "under-clay," as it is called, is penetrated by numerous roots shooting down into it. Above the coal-seam we find another bed of clay or sand, which is called the "roof" of the coal, and in which are found numerous stems and branches of plants. Further in the coal itself the impressions of ferns and other plants are sometimes visible; and if a very thin section be examined under the microscope, thousands of spore-cases or seed-vessels may often be seen. Putting all these facts together, it becomes quite certain that coal is formed out of the remains of old vegetation; that the plants from which it has been formed actually grew on the spot where the coal is now found; that the "under-clay" is the old soil in which these plants grew; and that the "roof" represents the accumulation of sediment deposited on the vegetable remains after the old land surface had sunk beneath water.

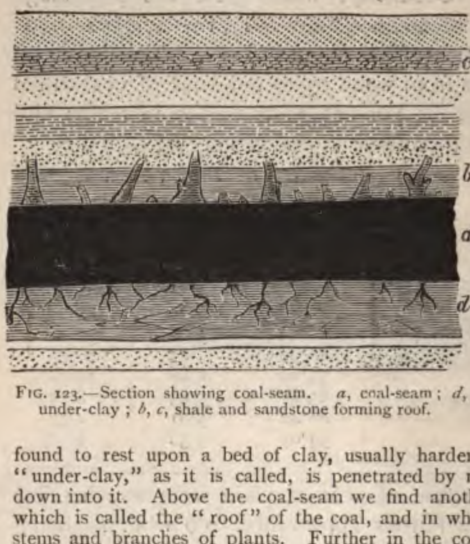


FIG. 123.—Section showing coal-seam. *a*, coal-seam; *d*, under-clay; *b*, *c*, shale and sandstone forming roof.

It has been found that the vegetation out of which coal has been formed indicates a warm moist climate and a low marshy district. Numerous ferns, some of very large size, were found; and huge reed-like plants having

a jointed fluted stem, and known as calamites, were abundant. An enormous number of plants related to our club-mosses, but reaching the size of ordinary trees, flourished. Of these, the lepidodendron and the sigillaria are noteworthy. The stems of the lepidodendron were marked with lozenge-shaped scars; the sigillaria had cylindrical fluted stems of great height, marked longitudinally with leaf-scars, and having long spirally pitted roots called stigmaria. All these belonged to the class of flowerless plants; but in addition to these a number of true trees related to the pine and yew have been noticed.

Coal, then, may be regarded as composed of the remains of the stems, branches, leaves, and spores of ferns, calamites, lepidodendra, sigillaria, and pines. Numerous generations of these plants lived and died, so as to heap up a great thickness of vegetable remains, and in time the surface of the land where this accumulation was taking place sank beneath the sea. Most of the trees were overthrown, but others remained standing until the whole was buried beneath the sand and clay deposited around. This accounts for the "roof" of the coal-seam so often containing the upright stems of trees. The vegetable matter thus entombed remained for thousands of years, undergoing changes due to the great pressure upon it and the chemical actions going on within it. After a long period this old land was raised again a little above the level of the sea by deposits of mud, etc., and another rank and luxuriant vegetation began to grow. The land sank once more, sand and mud again covered the vegetation, and a second coal-bed was formed above the first. By repeated depressions it is easy to see that several coal-seams might be formed in succession over the same area.

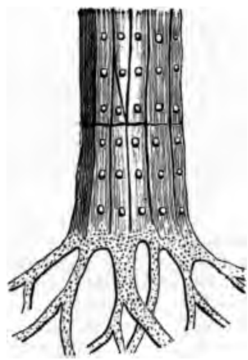


FIG. 124.—Sigillaria stem with stigmaria roots.

137 (*c*). **Chemically formed Stratified Rocks.**—This division includes all those rocks formed of material that has been dissolved by various natural waters, and then deposited by the chemical process of precipitation. It therefore includes some limestones, for besides the limestones already described (the

organic limestones, chalk, and coral), there are masses (calcareous rock that have been deposited from solution.

It must be remembered that pure water does not dissolve calciun carbonate (carbonate of lime), but only water containing carbon dioxid in solution. Rain-water always contains a certain amount of carbon dioxid dissolved out of the air, and this quantity is sometimes greatly increase as the water passes through decomposing organic material in the rocks Besides, during its underground course the water is often under grea pressure, and it can then hold more carbon dioxide and dissolves mor carbonate of lime than at the surface. As the air is reached some of th carbon dioxide escapes, and part of the carbonate of lime is precipitated Such springs, on reaching the surface, deposit a film of carbonate of lim on everything around, and if birds' nests or bits of wool be left in the spra from such a spring they soon acquire a coating of this substance. Popularly springs like this are called *petrifying* springs (Lat. *petra*, a rock or stone) But it is a mistake to suppose that the substance has been turned into stone it has only received an outer covering or incrustation of carbonate of lime But before such springs come to the surface much work has been done b the water. Great cavities are frequently formed in limestone rocks by th solvent power of the water thus charged with carbon dioxide. Sucl caverns are frequent in the limestone districts of Derbyshire and othe parts. Not only are caverns thus formed by masses of rock being dissolve away, but curious effects are sometimes wrought within these caverns. A the water hangs on the roof, some of it evaporates, and thus deposits portion of the limestone held in solution. In process of time there is formed in this way, a pendant mass of calcium carbonate like an icicle. This i called a *Stalactite.* Some of the water dropping on the floor gives up, o further evaporation, more of the limestone in solution, and thus a projectio rises on the floor of the cavern like the one on the roof. This is called *Stalagmite.* At times the stalactite from the roof and the stalagmite fro the floor meet and form a continuous column, as is shown in Fig. 3 *Travertine*, or calcareous tufa, is a porous friable limestone deposited the surface, often on a hill-side, by the waters of a calcareous spring.

Beds of *rock-salt* (sodium chloride, NaCl) several hundred feet in thic ness are found in Cheshire, Bohemia, and other places, and these be must have been formed by the evaporation of bodies of water. The Dea Sea and the Great Salt Lake of Utah are examples of great enclosed sa lakes, which were originally fresh, as is shown by the freshwater organism found on their shores. The water of these lakes is carried off by evapor tion as fast as, or faster than, it is brought in, and hence the amount dissolved matter increases. The valley of the Dead Sea is the lowest the earth, the surface of the water being 1298 feet below the level of t Mediterranean. Its waters now contain 24 per cent. of salts by weigh or nearly seven times the proportion in ordinary sea-water. The Caspi and Aral seas were originally salt, being situated in a depression which believed to have once communicated with the Arctic Ocean, subseque elevation of the land having cut off the connection. Deposits of rock-sa are now forming on the beds of these lakes.

Dolomite is a chemical limestone that contains magnesian carbonate well as calcium carbonate. It is sometimes called *magnesian limeston* and has probably been formed by the percolation of water containing di solved magnesium carbonate through an ordinary limestone.

Gypsum is found as a deposit in the old beds of certain lakes that ha held this compound (calcium sulphate) in solution.

Sinter is a light, porous rock composed of silica that is deposited by evaporation around the mouths of geysers, and in the neighbourhood of some hot springs. Silica is quite insoluble in ordinary water, but the hot

FIG. 125.—Entrance to the Cave of Adelsberg (in Carniola, 22 miles N. of Trieste). Stalactites are seen hanging from the roof, stalagmites rising from the floor.

lkaline water of geysers, charged with soda or potash, can dissolve it. Minute plants belonging to the class algæ live in this heated water, and

secrete portions of the silica in solution. On their death they ai increasing the deposit of silica.

138. **The Igneous Rocks.**—Igneous rocks are rocks t have at some period been in a liquid state owing to inte heat, and that have then cooled from the state of fusion. T are placed in two great divisions termed *Volcanic* and *Pluto* the distinction being dependent upon the conditions un which the fused matter has cooled.

The Volcanic Rocks have been formed from molten ma that has either been sent to the surface of the earth, or su ciently near the surface to be relieved from pressure, so t they have cooled with comparative quickness in contact v

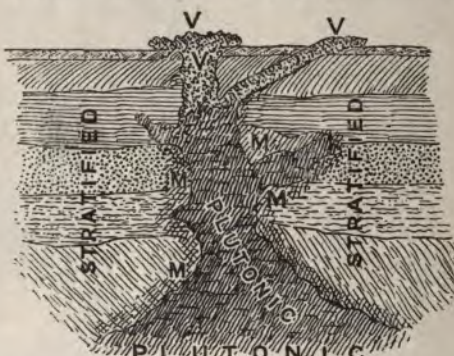


FIG. 126.—Diagram of the three great classes of rocks.
M = metamorphic; V = volcanic.

the air. Volcanic *ashes* and the different kinds of ejected *l* belong to this division.

The Plutonic Rocks consist of materials that have b forced as *dykes*[1] into fissures, or pushed as intrusive she between layers of stratified rock, so that they have coo slowly under great pressure. *Granite*, *Lyanite*, *Diorite*, a *Gabbro* belong to this division.

The distinction between the two classes gradually gets l as will be understood from the diagram (Fig. 126), where plutonic is seen passing upward into the volcanic. But

[1] The term *dyke* is used to describe the wall-like mass of igneous r filling a great fissure in the earth's crust.

distinction is important, because the rate of cooling affects the internal structure of the rock.

The volcanic rocks that have cooled rapidly have a glassy texture or are *hemi-crystalline*, *i.e.* have small crystals in a glassy ground-mass, while the deep-seated plutonic rocks are *holo-crystalline* (Gk. *holos*, whole), that is, crystalline throughout. We may tabulate the facts thus stated about the Igneous Rocks as below :—

Igneous rocks (cooled from a state of fusion).	Volcanic rocks (cooled at or near the surface, are glassy or hemi-crystalline).	Volcanic ashes and lavas.
	Plutonic rocks (have cooled below under pressure, are holo-crystalline).	Granite, syenite, diorite, and gabbro.

All these igneous rocks consist of chemical compounds termed silicates, with or without free silica; that is, they consist of silica united with one or more oxides of such metals as aluminium, potassium, calcium, magnesium, and iron, and some have a proportion of free silica besides. The relative proportion of silica in the igneous rocks, whether free or combined with metallic bases to form silicates, leads to their being divided into three divisions. Since silica acts as a weak acid, those igneous rocks that contain silica in large proportion (above 66 per cent.) are called *acidic rocks;* those igneous rocks that contain a relatively small per cent. of silica (45 to 55 per cent.), and a relatively large per cent. of metallic bases are called *basic rocks;* while those igneous rocks that have a percentage of silica from 55 to 66 are called *intermediate rocks*. The acid or highly silicated igneous rocks are often of light colour, and, being poor in lime, magnesia, and iron, are difficult of fusion. The basic or poorly silicated igneous rocks are darker in colour, of higher specific gravity than the acid rocks, and have no quartz or *free* silica.

The annexed table summarizes the information just given about the classification and composition of the igneous rocks, and it will aid us in describing each rock given in it.

Chemical division.	Mineral composition.	Plutonic: holocrystalline.	Volcanic.	
			Hemicrystalline.	Glassy.
Acid	Quartz, orthoclase felspar, and mica	Granite	Rhyolite	Obsidian pumice
Intermediate	Felspar (O. or P.) and hornblende	Syenite and Diorite	Trachyte and Andesite	Trachyte-glass
Basic	Plagioclase felspar and augite, with oxides of iron, lime, or magnesia	Gabbro	Basalt	Tachylite

After learning the above table, it will be easy to state, regarding any plutonic or volcanic igneous rock, its general chemical character, its mineral composition, its general internal texture, and the circumstances under which it cooled and consolidated.

139. **Volcanic Igneous Rocks.**—The two kinds of volcanic rock are *volcanic ashes* and *lavas*. Volcanic ashes consist of the dust and smaller fragments driven out from volcanoes, and these will be described in the next chapter. *Lava* is the name given to the more or less molten rock which rises up the tube or pipe of a volcano and flows out over the edge of the crater at the top, or forces its way through fissures in the side. Some lavas flow quickly, like molten iron, while others are less liquid, and move very slowly. In some cases the lava stream scarcely reaches the bottom of the mountain, but in other cases it runs many miles. The upper surface of a lava stream cools quickly, and has generally a cindery or *scoriaceous* appearance. It is full of small holes or cells formed by the escape of steam from its surface, so that it has a spongy texture. This gives it what is called a vesicular or cellular structure (Lat. *vesicula*, a small bladder). The lower portion of the lava stream is also cooled by contact with the rock beneath. In the middle, however, the lava stream cools very slowly, and acquires a more solid and glassy structure. The interior of a lava stream sometimes retains a great heat for several years.

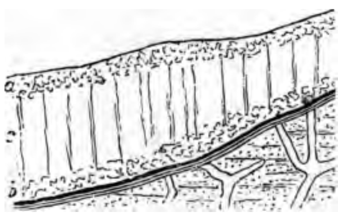


FIG. 127.—Section of lava stream. *a* and *b*, scoriaceous surfaces; *c*, solid interior.

The chief kinds of lava are given in the column headed "volcanic" in the preceding table.

Rhyolite and *Obsidian* are acid lavas having the same mineral composition as granite, but differing from granite in texture and mode of origin. *Rhyolite* (Gk. *rhyomai*, to flow) is an acid lava showing a striped flow-structure like many furnace slags, and consisting mainly of small crystals embedded

in a glassy ground-mass. *Obsidian*, or volcanic glass, is similar in composition to rhyolite, but having cooled quickly, it only shows a vitreous structure and resembles dark bottle-glass. *Pitchstone* is a duller variety of obsidian.

As lava rapidly cools into the vitreous or glassy state, a froth or scum, full of small elongated cavities formed by escaping steam and gases, is produced. This is *pumice*. Pumice, in fact, is the grey, rough, and porous variety of igneous rock formed from any glassy lava. It occurs both in the form of ejected masses and also on the surface of lava streams. With its cavities full of air after cooling, it is lighter than water, and floats, though if the pumice be reduced to powder it quickly sinks. After a time, floating pumice becomes water-logged, and sinks.

Trachyte and *Andesite* are intermediate lavas consisting of a variety of felspar combined with hornblende, but having no free quartz. Trachyte (Gk. *trachys*, rough) is usually grey, and has a rough, harsh feel; Andesite is somewhat darker, and has a greater proportion of plagioclase felspar than trachyte. It is common as a lava in the volcanoes of the Andes.

Basalt is a dense basic lava of a dark colour, that breaks with a conchoidal or shell-like fracture. It consists of plagioclase felspar and augite combined with certain metallic oxides, and shows a finely grained or hemi-crystalline texture in a glassy base. The basalt rocks are found both as intrusive masses and as sheets that have been poured out on the surface. Many of these lava sheets of basalt in slowly cooling and solidifying acquired a columnar structure, the columns often having a more or less hexagonal shape, though the number of sides varies (see Fig. 128). Interesting examples of these columnar basalts occur at Fingal's cave in the island of Staffa, and at the Giant's Causeway in the north of Ireland.

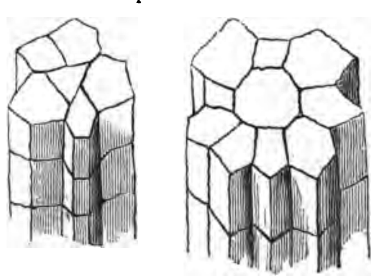


FIG. 128.—Columnar structure of basalt.

Trachylite is the quickly cooled glassy form of basalt, and but rarely found.

140. **Plutonic Igneous Rocks.**—As shown in the table of Igneous Rocks, the plutonic varieties belong to the three chemical divisions, but all show a distinct crystalline structure. *Granite* (Lat. *granum*, a grain) consists of crystals of orthoclase felspar, mica, and free quartz, arranged as a coarsely crystalline aggregate (par. 114). Many varieties of the rock are known, due to differences of texture and small differences in mineralogical composition. The felspar is usually orthoclase, and varies in colour from white to red. When the crystals of felspar are very large the rock is called a *porphyritic granite*. The mica in most granites is usually potash mica

(muscovite), and has a silvery lustre; in some granites, however, the mica is magnesia mica (biolite), and appears as a lustrous black mica. The quartz of granite usually forms a sort of matrix or bed for the crystals of

FIG. 129.—Giant's Causeway, Antrim: basaltic columns.

felspar and mica. It can be detected by its glassy lustre and by the failure of a knife to scratch it.

Granite not only occurs in large eruptive masses forming the central parts of many mountain chains, but also in smaller dykes, veins, and bosses. When granites are weathered—that is, exposed to the action of frost, heat, rain, and rain-water containing carbonic acid—the felspar crystals are slowly decomposed, and the rock crumbles away. The soluble potash and soda silicates in the felspar are washed away, but the silicate of alumina forms a white powder called kaolin, or china clay. The quartz breaks up into small grains, and the mica into thin flakes, and these grains form the sand found on the beds of rivers, and on the sea-shore, becoming more rounded and reduced the longer they are submitted to the action of the water. In time, and under suitable conditions, this sand may become consolidated into a sedimentary rock, and the sandstone thus formed may itself suffer disintegration (breaking up) and re-formation many times.

Syenite is an intermediate plutonic rock differing from granite in the absence of free silica (quartz) and in the fact that hornblende usually takes the place of mica. It was originally obtained from quarries at Syene in Egypt. *Diorite* is a syenite in which plagioclase felspar replaces orthoclase. It occurs in the Malverns and North Wales, and is quarried for sets.

Gabbro is a term applied to dark-coloured crystalline basic plutonic rocks that consist of plagioclase and augite with one or more basic oxides. A finer kind of gabbro is called *dolerite.*

141. **Metamorphic Rocks.**—Metamorphic rocks are rocks that have undergone extensive changes of structure since their first formation. Such transformed rocks are found either in *contact with* intrusive igneous dykes and sheets (Fig. 126), or in

those regions of the earth where the strata have been subject to enormous lateral pressure. The chief agents of metamorphism thus appear to be great heat with water and immense lateral pressure. The chief changes of structure effected by metamorphic action are crystallization and foliation. As examples of metamorphic rocks we may mention *marble*, *quartzite*, *slate*, *gneiss*, and the *schists*.

Crystalline Limestone, or statuary marble, is only limestone that has been altered by fusion so as to give it a granular texture like loaf sugar. Some marbles are coloured by mineral matter, and all are capable of being polished.

Quartzite is sandstone that has been hardened by partial fusion, so that the grains of sand have run together, and can no longer be obtained separate on breaking the mass.

Slate is shale that has been hardened and otherwise changed by intense lateral pressure, and is composed mainly of aluminium silicate. In speaking of shale we described it as a hardened clay that splits into laminæ or thin leaves parallel to the layers of deposition. This shale was formed by film after film of fine sediment having been placed one on another, and this compacted by pressure from above, so that the films or laminæ acquired a tendency to separate one from another like the leaves of a book. The shale has undergone further alteration by great lateral pressure, causing it to split or cleave into leaves in a direction different from the bedding ; and such altered shale is called slate. *Cleavage*, or slaty cleavage, is the name given to the tendency found in some rocks to split into layers or flakes more or less perpendicular to the original layers of deposition ; while *lamination* (Lat. *lamina*, a leaf) is the name given to the arrangement in thin layers parallel to the bedding. Shale has a laminated structure, but slate shows cleavage.

Gneiss.—Gneiss is composed of the same minerals as granite, viz. quartz, felspar, and mica, but the minerals are arranged in layers or bands. Rocks in which the minerals are arranged in layers are said to be *foliated*, and this foliated arrangement of the minerals is the great peculiarity of gneiss. It occurs among the oldest known rocks of the earth's crust. Here is a drawing of a piece of gneiss, showing the foliated arrangement of the component minerals. The light layers consist of granular felspar, with here and there a little mica and quartz. The dark bands indicate layers of black mica intermingled with grains of grey quartz. The rock will split most easily along the dark layers.

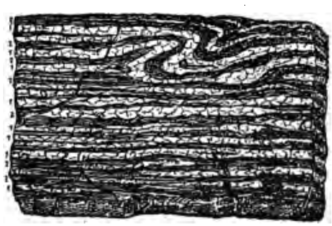


FIG. 130.—Gneiss.

The term *schist* (Gr. *schizo*, to split) is applied to any metamorphic rock that actually splits into folia or leaves not parallel to the original bedding. Those schists that have had their constituent minerals re-crystallized and re-arranged are called *crystalline schists*, and are named after their predominating mineral. Thus *mica-schist* is a crystalline metamorphic rock consisting of irregular wavy layers of mica and quartz.

CHAPTER XIV.

INTERIOR OF THE EARTH—VOLCANOES; EARTHQUAKES, AND OTHER MOVEMENTS OF THE EARTH'S CRUST.

142. **Density of the Earth.**—Astronomers have been able to calculate the weight of the earth, and have shown that it is about $5\frac{1}{2}$ times heavier than a globe of the same size composed of water. The mean density or specific gravity of the materials that form the crust is a little less than 3. The average density of the earth is thus about twice the density of the rocks forming its crust. We are, therefore, forced to conclude that the interior portions of the earth are specifically heavier—*i.e.* of greater density—than the outside crust. The explanation of this increase of weight in the materials of the earth's interior is a question still in dispute. In consequence of the enormous pressure exerted on the rocks in the interior by the rocks overlying them, some assert that these deeper rocks, composed of the same kind of materials as those in the crust, will be compressed or squeezed into so much less space, that this increase of density is easily accounted for, and that the increase of density would be still greater were it not for the expansive force of the heat in the earth's interior. Others doubt this great compressibility of solid substances, and believe that the interior portions of the globe are composed of heavier and different materials than those near the surface. These materials are thought to consist largely of metallic elements, such as iron, nickel, and cobalt, either free or forming alloys with one another. It has been pointed out that in this respect the earth's interior would be similar in composition to those pieces of matter flying through space which sometimes fall on the earth as *meteorites.*

143. **Internal Temperature of the Earth.**—A thermometer on the surface of the earth, or buried only a few inches below the surface, shows variations of temperature depending on the time of the day and the season of the year. But these variations do not penetrate far into the crust. At a distance below the surface of about fifty feet in Britain there is a stratum of invariable temperature, this constant temperature being usually nearly the same as the average temperature of the surface. The depth at which this constant temperature is found varies somewhat with the climate. Below this depth the temperature increases, so that at the bottom of a deep mine the miners usually take off their clothes. The rate of increase varies for different places, being on the average 1° F. for every 60 feet of descent, or 88° F. for every mile. These facts have been ascertained by taking the temperature in mines, borings, and deep wells. In the Rose Bridge Colliery, near Wigan, a shaft has been sunk to the depth of 2445 feet, and the temperature at the bottom is about 94° F., the average temperature at the surface being 49° F. This gives an increase of about 1° F. for every 54 feet. Water rises from an artesian well near Paris from a depth of 1800 feet, and this water has a temperature of 82° F., being about 29° more than the average temperature. Other proofs of the high temperature of the interior of the earth are found in the existence of volcanoes sending out molten masses of rock, and in geysers and other hot springs discharging large volumes of heated water. These hot springs occur most frequently in the neighbourhood of volcanoes, but they are also found in other districts. There is one at Bath, the waters of which have a temperature of 120° F.

144. **Interior not Fluid.**—But though there is thus a high temperature existing in the earth's crust, and though there is a more or less regular increase of temperature with depth, it does not follow that the interior of the earth is in a liquid state. If the rate of increase (1° F. for every 60 feet) continues to depths far below those observed, it is certainly true at a depth of about two miles the rocks would be as hot as boiling water, while at a depth of forty or fifty miles the heat would be sufficiently great to melt any rock if *at the surface*. But at such a depth the pressure would be very great, and under increased pressure the melting-point of solid bodies is raised. They require more room when melted than when solid, and if the pressure prevents them from getting that space they cannot melt. We thus see that even if the temperature at great depths be above the fusing-point of the rocks, they may be kept in the solid state by intense pressure. But we are not certain that the temperature at great depths does follow the regular law of increase observed in the rocks of the crust. In some places the increase of temperature is much greater than the average given above, and in some places much less. It varies from 1° F. for every 20 feet of depth to 1° F. for every 100 feet. It has been noticed that the rate of increase is very high in places that have been recently the seat of volcanic activity. It may be pointed out that the calculations of astronomers show that the observed motions of the earth are inconsistent with a fluid interior. The most probable conclusion, therefore, is that the earth is mainly solid throughout, but that liquid spaces or cavities are formed by diminution of pressure or the inflow of water, both of which might reduce the fusing-point of the rocks, and from these spaces volcanoes derive the material which they eject.

145. **Definition of a Volcano.**—It is not easy to give a satisfactory definition of a volcano, but we can easily avoid

some of the mistakes often committed, and on which we shall afterwards remark. Here are examples of more or less accurate and complete definitions which will serve our purpose, and which will be better understood shortly. "A volcano is a more or less conical hill or mountain, usually truncated, communicating with the interior of the earth by a pipe or funnel, through which issue hot vapours and gases, and frequently loose fragmentary materials, and streams of molten rock."—*Prof. J. Geikie.* "A volcano is a more or less flat cone which is, or has been, connected by a channel with the depths of the earth, and which serves, or has before served, as an outlet for gaseous, solid, and glowing liquid masses."—*Credner.*

It will be noticed that in this last definition there is implied the fact that some volcanoes cease to send forth materials and become inactive. Hence the distinction between *active* and *extinct* volcanoes. "An active volcano may be defined as a passage or pipe which affords to deep-seated mineral matter in a state of fusion the means of transmission through the earth's crust, and of egress at its surface. A passive or extinct volcano is one in which this communication is obstructed, either by a plug of solidified lava, or by accumulations of fragmentary matter—a dissipation, temporary or permanent, of the eruptive energy permitting the solidification of the molten matter. Should an augmentation of the eruptive force occur, the plug will either be shattered and ejected in the form of lapilli and ashes, or re-melted and poured out as lava; but if it be unable to reopen the old passage, new vents may be produced, either within or without the lip of the crater."—*Rutley.* It will be noticed that in the definition of an active volcano, last given, no mention is made of a hill or mountain. No doubt this is because the essential and most important part of the volcano is the pipe or tube through which the ejected materials are sent, and also because the hills or mountains, when present, are built up out of the materials sent out, and are thus the results, and not the causes, of the volcanic activity. In the definition of an extinct volcano we must also notice that though no volcanic action of any kind is now taking place, yet it is possible that activity may again burst forth. Before A.D. 79 Vesuvius might have been regarded as an extinct volcano, for the great crater called Somma, which then occupied the summit, had never been known to be in activity. But in that year it came into sudden activity; half of the crater was blown away, a great eruption took place, and the new crater, the present Vesuvius, was formed within the old one. It has continued in activity at intervals ever since, new cones being frequently formed, or old ones altered in shape. In the Auvergne district of Central France many denuded cones of extinct volcanoes still exist. No record or tradition of any eruption, however, remains. Even when the cone has entirely disappeared, the neck or solidified plug of lava may still remain to fix the site of a volcanic vent. When a volcano only throws out steam and gases, it is said to be *dormant*, or in a quiescent state. Renewed activity may occur at any time. A dormant volcano usually forms only a small cloud of steam near its summit.

146. **Signs of an Eruption.**—In some cases eruptions ta place without any warning symptoms, but in other cases the are indications for various periods beforehand. Loud rumbli sounds are heard from the mountain, and as these increase intensity shocks of earthquake follow the noises, and the qua ings return at shorter and shorter intervals. These form o of the surest and most general signs of an eruption, especial when the volcano was previously quiet. The water in we and springs sometimes ceases to flow. This is no doubt owi to the disappearing of the water into rents and fissures belo At other times springs issue forth in fresh places, or wells whi were before pure become muddy. The sea, too, may be affect by the ground shocks, rising and sinking in an unnatural wa But all these signs may fail and the eruption come qui suddenly, as did that of Vesuvius in 1853.

147. **Phenomena accompanying an Eruption.**—After t signs and warnings, or without them, as may be, the vapo from the crater at the top of the vent increases in volume whi the lava ascends in the pipe or funnel, and the phenome usually occur in the following order:—

(1) The outbreak begins with a mighty shake of the mountain, and t highly expanded steam and gases burst forth, scattering in tremendc explosions minute fragments of the lava. These explosions are quick repeated, and huge ball-like masses of steam are driven upwards towar the sky. If there is little wind these rise nearly straight up and then spre out to form a horizontal cloud, so that the appearance of the column a cloud is like that of an Italian pine-tree called the stone-pine. This pi tree column, consisting of steam, gases, and fine particles of volcanic du reflects the glowing redness of the masses of heated rock and molten la in the crater below, producing the appearance of flames. That they are n real flames, but produced by the reflection of the lava glow in the cra on the millions of steam bubbles in the column, is evident from the fa that they show no fluttering motion, and are not driven out of their stea ness by any wind. The steam-cloud soon begins to condense, and a gre downfall of rain occurs, sweeping the loose volcanic dust down the slo of the mountain, and forming torrents of mud-lava that often do mo destruction than the real lava stream. Lightning and thunder accompa such an eruption, the electricity being probably generated by intense fricti of the steam and dust particles.

(2) Closely following and partly accompanying the outburst of stea and gases there is a great discharge of dust, ashes, and stones. These a derived partly from the lava in the funnel, and partly from the walls of t crater, and either fall back on the sides of the cone, increasing the size the mountain, or into the crater, whence they are again ejected, each ti being reduced to finer powder. Some of the very fine powder is carried

a great height in the steam column, and may be driven immense distances by the wind.

(3) The lava itself rises up the central funnel, and either overflows the lip of the crater or bursts its way through fissures in the sides of the cone. In this case there form on the hill secondary centres of eruption, throwing out cinders and ashes, and building up small *parasitical cones* on the sides.

FIG. 131.—Vesuvius in eruption, October, 1822, showing pine-tree column of steam, falling rain, ashes, and flashes of lightning.

From the streaming lava itself great clouds of steam arise. The outflow of lava usually marks the crisis or culminating point of the eruption.

This sequence of events is not always followed, and there have been many eruptions where only steam and ashes have been sent forth. At other times there has been a great outburst of lava with little steam and ashes.

148. Products of an Eruption.—We may place the products of eruption under the following heads: (1) steam and gases; (2) fragmental materials; (3) lava.

(1) *Steam and Gases.*—The most abundant of the substances ejected is steam or water gas. As before stated, it is erupted in large globular masses, each of which is the product of an explosion in the molten lava of the funnel or crater.

But besides steam there are the following gases: carbonic acid, hydrochloric acid, sulphur dioxide, sulphuretted hydrogen, sulphuric acid, nitrogen, and ammonia. Some of these volatile substances react on one another and on the heated rocks, forming a number of secondary products. Thus the sulphuretted hydrogen and the sulphur dioxide produce by their reaction water and free sulphur ($SO_2 + 2SH_2 = 3S + 2H_2O$). This free sulphur thus produced, not sent out of the volcano as such, is deposited in the fissures and cavities of the crater.

The hydrochloric acid acts on the rocks, uniting with the iron to form

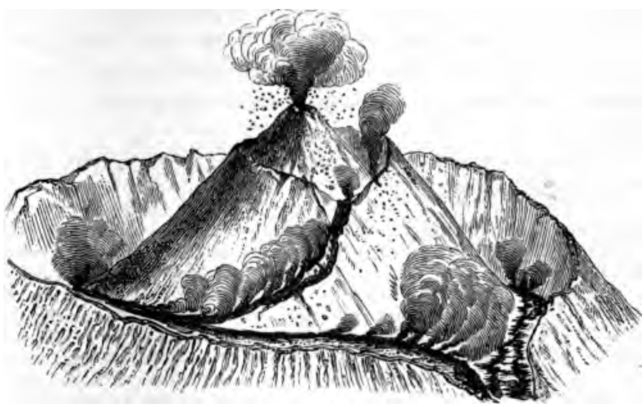


FIG. 132.—Summit of Vesuvius in 1756.

yellow ferric chloride. The acid gases form with the heated lavas other soluble salts, as sulphates, chlorides, carbonates, etc. The free hydrogen is inflammable, and burns with a pale blue flame, which is sometimes coloured by metallic oxides; but, as already remarked, the huge red glow so conspicuous at night is not due to flame, but is only the reflection on the steam-cloud of the heated lava below.

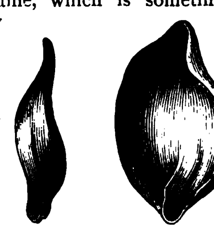


FIG. 133.—Volcanic bombs.

(2) *Fragmental Products.*—These consist of the solid materials sent out during an eruption, and are of various sizes and kinds. Some of the broken material is formed of pieces torn off the rocks through which the eruption has occurred, but most of it consists of ragged cindery lumps blown away from the lava bubbling and seething below. The larger angular pieces are spoken of as *volcanic blocks*. At

times masses of fluid lava are sent spinning into the air, and these during their rotation acquire a globular, oval, or pear-shaped form, and hardening as they fall are called volcanic bombs. A *volcanic bomb* is thus a round, oval, or pear-shaped mass of cooled lava that has acquired its form when rotating in the air. It may vary in size from a few inches to two or three feet in diameter. It is often cellular inside, the lava having been distended with bubbles ; sometimes hollow, but occasionally it has a solid nucleus.

Scoriæ or *cinders* is the name given to the rough, angular, cindery-looking material sent out from the volcano, or forming the slag and scum on the surface of some lava streams. The word " cinders " only refers to the appearance of the substance, and does not mean that it is a partly burnt fuel like the cinders of a fire. Scoria resembles more the slags and clinkers of an iron furnace, which are the partly fused glassy rock.

Pumice is the light, porous, rocky material sent out from the crater or formed on the surface of glassy lavas. Its composition and description will be found in a previous paragraph (139).

Lapilli are small ejected volcanic fragments varying in size from a pea to a nut.

Volcanic ash or *dust* is the fine light grey powder or dust formed partly from the bubbling lava, and partly by the attrition or friction of the ejected loose materials. These often fall back again and again into the crater, and are thus reduced to smaller and smaller particles, some as large as sand grains, but others finer than the finest flour. It is so called from its resemblance to the ashes of our fires, not because it is the incombustible mineral residue of a fuel. So minute are the particles of this volcanic dust that it readily finds its way through the smallest chinks into houses, boxes drawers, etc. This finely divided volcanic dust is sometimes carried by the steam column to a height of several miles, and then borne away by the upper currents of the atmosphere to very great distances. Dust from the Icelandic volcanoes, for instance, has often been known to fall in Norway and Sweden. The eruption from Vesuvius in 472 A.D. carried ashes over as far as Constantinople. It has even been met with by ships at sea at a distance of more than 1000 miles from the volcano that has thrown it out. In this way volcanic dust becomes spread all over the ocean. Some of the pumice sent out from volcanoes is also cast into the sea, and carried away by the waves far from land. In time this pumice sinks. There is thus formed on the floor of the ocean a deposit of these volcanic materials, so that from the deeper portions (above 2000 fathoms), where no sediments are brought, and where no calcareous remains fall, as they are dissolved before they reach the bottom, pumice and ashes have been dredged up, as well as certain red, grey, and chocolate-coloured clays, due to the decomposition of these volcanic materials. The presence of this deposit of red clay was one of the most important facts discovered in the expedition of the *Challenger*. The colours are due to the presence of oxide of iron and oxide of manganese. A remarkably violent eruption took place on the small island of Krakatoa,

in the Sunda Straits, between Java and Sumatra, during the year 1883. Up to May, 1883, the volcano, which formed a peak nearly 3000 feet high, had been inactive for a long time. In that month shocks began to be felt, and steam was seen issuing from the summit. The activity of the volcano gradually increased, until a series of tremendous explosions on August 26 and 27 blew away the cone and the greater part of the island. The sea in the neighbourhood was thrown into huge waves, which, sweeping over the coasts of Java and Sumatra, destroyed several villages, and drowned 30,000 people. Immense quantities of pumice, lapilli, ashes, and the finest dust were thrown into the atmosphere. Ships within a distance of twenty miles were in total darkness during the 27th, and the dust was observed falling by vessels at a distance of 1000 miles. The sea was covered for several weeks with a great thickness of floating pumice. So great was the concussion produced in the atmosphere that the air-vibrations disturbed the whole atmosphere of the globe. The finest particles of dust remained for a long time floating in the upper currents of the air, and were carried by the wind all over the earth. The presence of this impalpable volcanic dust caused a peculiar glow in the sky at sunrise and sunset for several months in nearly every country, and rain and snow which fell in Spain and other distant parts were found to contain the same materials as those forming the ashes from Krakatoa.

149. **Lava Streams.**—The composition and varieties of lava have already been described in speaking of igneous rocks. The rate at which a lava stream flows varies considerably. Sometimes it flows down the mountain cone like a rapid river, but usually it is very viscous and flows slowly. The slowly moving lavas have a wrinkled and twisted surface like coils of rope, but the currents that move quickly usually give off great quantities of steam, and this causes the upper layer to become scoriaceous or cindery. It thus appears that a large mass of water imprisoned in the lava increases its mobility. This upper layer of scoriæ is very vesicular, and the ragged, rough masses are very difficult to walk upon. A section of lava stream has been shown and described in Fig. 127. All rocks are bad conductors of heat, and therefore when once a solid crust has formed, the interior portion retains its heat for a long time—in very thick lava streams for many years. During the slow cooling it often splits up into more or less regular columns, such as those seen in the mud of a dried-up pool. This explains the columnar structure of basalt already referred to (par. 139).

It should be remembered that the fine ashes, lapilli, pumice, bombs, and scoriæ are all formed from the lava, and have therefore the same composition as the lava from which they are derived.

As already mentioned, lavas are mainly silicates of the following metals —aluminium, magnesium, calcium, iron, potassium, sodium—in varying proportions; these silicates being formed by the union of the binary compound silica (SiO_2) with the oxides of these metals. The acid lavas, or those containing a large proportion of silica (66 to 80 per cent.), as trachyte, are lighter in colour and more difficult to melt than the basic lavas, as basalt—which only contain 45 to 55 per cent. of silica. In all cases oxygen forms nearly one-half the weight of all lavas (see par. 139).

Some lava currents are congealed before they reach the bottom of the cone, while others reach many miles. Lava streams from Vesuvius have several times reached the sea, a distance of about five miles. A stream came from one of the numerous lateral cones of Etna of 1669 which reached a length of fifteen miles, with a width in some places of five miles. It ran the first thirteen miles in twenty days. In 1783 a stream fifty miles

long and twelve miles broad issued from Skaptar Yokul in Iceland. Where a volcano reaches above the snow-line, like Cotopaxi, the outpour of lava sometimes produces great floods. Eruptions occasionally take place beneath the surface of the sea, throwing up huge columns of water, and in some

FIG. 134.—Breached pumice cone with obsidian lava stream.

cases causing an island to appear. In 1831 an island called Graham's Isle was thrown up off the coast of Sicily to a height of 600 feet by a submarine eruption. In the course of a few months, however, this scoria cone was washed away by the waves, and the materials spread over the sea bottom.

150. **Cause of Eruptions.**—It is plain, from the enormous discharge of steam during volcanic eruptions, that the vapour of water plays a very important part in these phenomena. The expansion of large volumes of steam when under great pressure is believed by many writers to be the chief cause of the rise of lava, as well as the cause of the ejection of the cinders and ashes. When the water penetrates into the cavities where molten matter is present, the steam generated is thought to exert such force as to press up the lava in the duct of the volcano, and then burst in huge bubbles as the pressure on it lessens near the surface. Other writers state that the rise of lava is due to a slight shrinking and contraction of the earth's crust.

151. **Structure of Volcanic Mountains.**—The cones and craters of volcanoes have many varieties of form, and during an eruption great changes are often produced. They range in height from a few feet to nearly four miles. Vesuvius is not quite 4000 feet, Etna is 11,000 feet, and Cotopaxi, in Peru, 18,876 feet. The cone which constitutes the mountain is built up of the materials ejected from the crater, though some of the finer materials are carried, as previously shown, by the winds and distributed over the sea and distant lands. The materials, however, mostly descend round the spot where they are thrown out, and the thickness of the deposit becomes less and less at a greater distance from the vent. There is thus built up a conical structure, truncated or cut off at the top, the materials of the sides of the cone being arranged in layers sloping outwards, but the materials that fall within the crater slope inwards. In some cases, owing to the action of the wind, the cone is much higher on one side than on the other.

Some cones are built up almost entirely of scoriæ or cinders, and these constitute the fragmentary materials sent out. There is a large number of such *cinder-cones* among the extinct volcanic peaks in the Auvergne district. In the Lipari Islands are found cones almost entirely composed of pumice. Such *pumice-cones* have been formed of the material exploded from the surface of a glassy lava.

Some cones are mostly formed of the smaller fragmentary materials called lapilli and ash. As already explained, rain often causes this to come down as mud, which consolidates in layers of volcanic tuff or tufa. The *tuff-cones* have not such a steep slope as the cinder-cones.

There are cones composed partly of scoria and partly of tuff, the materials being arranged in layers so as to have a stratified arrangement.

Cones are found which are almost entirely composed of lava flows. The lava, as it wells out, either accumulates in dome-shaped masses or spreads out on all sides in such a way that a great conical heap is formed with a very wide base. The great volcano of Mauna Loa in the island of Hawaii, one of the Sandwich Islands, is a lava cone, and has a height of nearly 14,000 feet, and a breadth at the base of seventy miles. The slope is therefore very small compared with the slope of such volcanoes as Etna and Vesuvius. Its crater is a huge pit two or three miles across and over 700 feet deep, at the bottom of which is liquid lava. Kilauea is another great crater on the side of the same mountain, but sixteen miles distant from Mauna Loa. The crater is several hundred feet deep and nearly three miles across. In the centre of this huge pit is a seething, fiery, liquid lake of lava. The molten rock heaves and bubbles with the fluidity of molten iron, dashing in waves against the solidified walls of lava, or throwing up on its surface cones and fountains of lava. At intervals of a few years the fiery liquid rises up to the brim of the crater and overflows, or, as is more usual, bursts through rents in the side of the mountain. The two craters do not appear to have any connection, though situated on the same mountain, and they are different from most other volcanoes in only discharging lava, which is of a very glassy kind, and in their discharges being seldom accompanied by any great explosions.

But most of the volcanic mountains of the globe are built up partly of fragmentary materials and partly of lava that has run down the sides. These alternate in such a way as to give the cone a stratified appearance when seen in section.

Such cones are called *composite cones.* Here are two views of such a cone, the first exhibiting the cone as seen from above, and the second showing it in vertical section.

But even this view of a composite cone is not quite complete. As the molten lava is being forced up from below, some of it is injected into cracks and fissures in the cone, and at times one of these fissures opens on the flanks of the cone, and a small lateral cone is then produced. But

much of the lava injected into these fissures solidifies there, and forms veins or walls of rock known as dykes. These dykes traverse the layers of ash, tuff, and lava previously sent out. Fig. 136 is an ideal section of such a dyke-traversed composite cone, showing also lateral parasitic cones. We

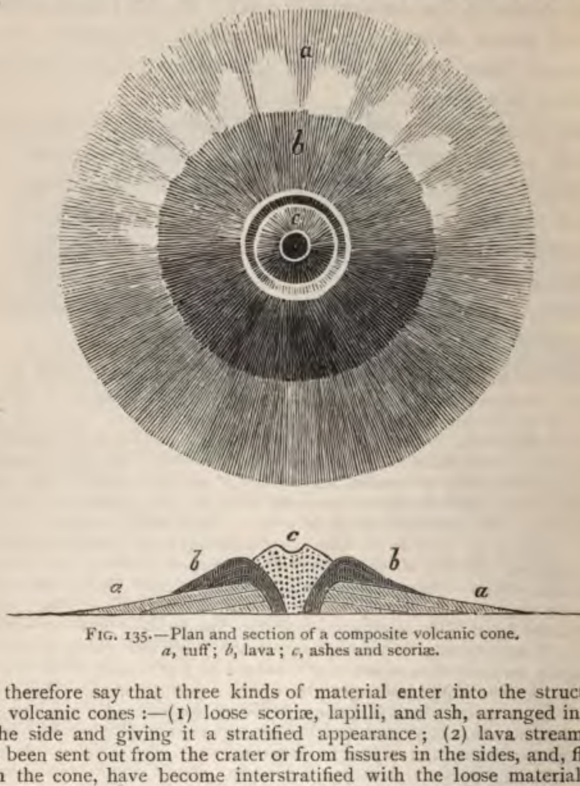


FIG. 135.—Plan and section of a composite volcanic cone. *a*, tuff; *b*, lava; *c*, ashes and scoriæ.

may therefore say that three kinds of material enter into the structure of most volcanic cones:—(1) loose scoriæ, lapilli, and ash, arranged in layers on the side and giving it a stratified appearance; (2) lava streams that have been sent out from the crater or from fissures in the sides, and, flowing down the cone, have become interstratified with the loose materials; (3) dykes or masses of lava filling up cracks and fissures in the cone.

152. **The Crater** of a volcano is the cup-shaped depression or chasm found at the summit or on the flanks of the hill, and at the bottom of which is situated the duct or pipe that communicates with the heated interior. It has usually a circular form, owing to the expansion in all directions of the explosive vapours that rise from below. Craters vary in size, some of the very large ones being more than a mile in diameter and more than a thousand feet deep. The inner walls of the crater frequently present a rough and rugged appearance. The bottom of the crater when quiescent is a rough plain, with here and there heaps of loose material *giving off* steam and hot vapours. At night the glowing lava may be seen *through* fissures.

153. **Errors about Volcanoes.**—We often find, especially in older books, many mistakes in the definition of a volcano. For example, a volcano is often described as "a burning mountain sending out fire and smoke from its summit." Now, as we have seen, the essential part is the

Fig. 136.– Ideal section of volcano showing dykes of lava and lateral craters forming lateral cones.

duct or pipe communicating with the heated interior, and at the beginning there is often no mountain at all, the mountain being built up of the materials ejected. The fiery glow that is usually seen is not due to burning or combustion, for this and the supposed flames are caused by the reflection in the steam-cloud of the red-hot lava in the crater below. What is spoken of as "smoke" is only the condensing water vapour sent out in great globular masses from the heated lava. Real steam is invisible, but as soon as it comes into contact with the colder air it begins to condense into minute particles of "water-dust." These minute particles of water-dust form what is usually spoken of as the steam column, which after attaining a great height is still further condensed, and falls in drops as rain. Nor does the volcanic action always take place at the summit of the hill where one has been formed, as eruptions frequently occur through fissures formed in the sides.

For more correct definitions than the above, see paragraph 145.

154. **Number, Position, and Distribution of Volcanoes.**—The number of active volcanoes now found on the surface of the earth is a little over 300. If we include those extinct volcanoes which still possess a conical form and signs of a crater, we shall probably find the total nearly 1000. One of the first things to notice regarding the *position* of volcanoes is the fact that they are mostly situated near the sea, on islands, or on the borders of continents. The only exceptions to this rule are five or six volcanoes said to exist in Central Asia, in the Thian Shan Mountains and Manchooria, and two or three in Central Africa.

Another interesting fact regarding their position is that they are found in all regions of the globe, from Iceland and the Aleutian Islands, through the tropics to the Antarctic continent, though they are more numerous in the torrid than in any other zone. They seem to follow certain lines, as will be seen on reference to the map. Over 200 of the active volcanoes, too, are found on the coast-lands or islands of the Indian and of the Pacific Oceans. On the east side of the Pacific we can trace a line of volcanoes through the lofty chain of the Andes, then through Central America and along the *west coast of North America.* The volcano of Jorullo, on the coast of the

Mexican table-land, is noteworthy from the fact that it was entirely built up to a height of over 1300 feet in a single eruption in 1759. This line then crosses over from North America by the Aleutian Isles to Kamtschatka on the western side In Kamtschatka there are 12 active volcanoes, in the Kurile Islands 10, and in the Japanese islands over 20. From Japan the line of volcanoes passes through Formosa and the Philippine Islands to the Malay Archipelago. In this great group of islands volcanic activity seems at its height. In Java there are about 40 volcanoes, and in Luzon and the Philippines 21. In the Malay Archipelago the volcanic line bifurcates. One branch goes westward through Java and Sumatra, along the eastern side of the Bay of Bengal; another branch turns to the south-east through Celebes, New Guinea, the Solomon Islands, and the New Hebrides. A continuation of this line passes into New Zealand, and to Mount Erebus and Mount Terror in the Antarctic continent. Another great volcanic line may be traced down the eastern side of the Atlantic, from Jan Mayen and Iceland through the extinct volcanoes of the Faroe Islands and those of the west of Scotland to the Azores, Canaries, Cape Verde, and other volcanic islands lying off the coast of Africa. This line appears to be connected with a great submarine ridge that runs down the middle of the Atlantic. One branch from this passes into the West Indies, where there are six active volcanoes, while another branch passes into the Mediterranean. Vesuvius is the only active volcano on the mainland of Europe, but on the islands of the Mediterranean there are four or five—viz. Stromboli and Vulcano in the Lipari Islands, Etna in Sicily, Santorin and Nisyros in the Grecian Archipelago. It is believed that this linear arrangement of volcanoes is owing to the fact that they occur on lines of fissures in the earth's crust. The great volcanic bands just described run very near to the lines of great mountain chains, and probably owe their positions to the great lines of fissures on the globe. Even in a smaller group, as on the island of Vulcano, the craters often show this linear arrangement, although there are some cases where the vents do not follow the line of fracture in the earth's crust.

155. **Solfataras, Mud Volcanoes, etc.**—After the energy of a volcano has declined, it sometimes passes into what is called the *Solfatara stage.* A solfatara consists of cracks or fissures from which various kinds of vapours are sent forth. These vapours contain sulphur, chloride of sodium, alkaline sulphates and other substances, and these are often deposited on the lips and sides of the orifices. The smoking cracks in Tuscany are known as *suffioni*, and the issuing vapours contain boracic acid. *Fumaroles* are fissures, often on the surface of a lava-flow, from which steam and other gases are ejected. *Mud volcanoes* or *Salses* are vents from which mud and water are ejected. The mud usually forms in a conical mound around the orifice, but this seldom rises above twenty or thirty feet. There are groups of mud volcanoes in Trinidad and in the neighbourhood of the Caucasus Mountains, the discharge from which contain naphtha and petroleum.

156. **Earthquakes.**—Earthquakes are vibrations, or forward and backward motions of the ground, caused by a wave of elastic compression passing through the crust of the earth. That the movement is of the nature of a wave is evident from the fact that it is not felt at the same time and with the same force over the whole of the district affected. It appears to


Showing Distribution of
VOLCANOES AND EARTHQUAKES
The earthquake districts thus
the deeper tints indicating more
frequent and violent shocks
Active, dormant and recently extinct
Volcanoes are indicated by dots
ARCTIC OCEAN
GREENLAND
Baffin Bay
Davis St.
Jan Mayen
Arctic Circle
Iceland
BRITISH ISLES
EUROPE
ASIA
NORTH AMERICA
SOUTH AMERICA
AFRICA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
ANTARCTIC OCEAN
Tropic of Cancer
Tropic of Capricorn
Equator
Antarctic Circle
Aleutian Is.
Sandwich Is. (Hawaii)
Friendly Is.
Society Is.
Low Arch.
Galapagos Is.
Bermudas
Bahama Is.
W. Indies
Azores Is.
Canary Is.
C. Verde Is.
Desert of Gobi
Tibet
Laccadive Is.
Maldive Is.
Madagascar
Sumatra
Java
Philippine Islands
Japan Is.
Kurile Is.
Caroline Is.
Solomon Is.
Fiji Is.
Crozet Is.
Kerguelen
Enderby Ld.
South Shetlands
Wilkes Land
100 Long. W. 80 of Green. 60
60 Long. E. 80 of Green. 100
Edwd. Weller

MAP I.

start from a centre and spread out with diminishing intensity in all directions, and consists of several successive movements ending very gradually. Further, trees, steeples, and other tall objects have been noticed to sway backwards and forwards like the mast or funnel of a ship rocking on the sea. Besides this wave-like motion there is usually a vertical uplifting movement, and rumbling noises are heard both from the ground and in the atmosphere. The study of earthquakes is called Seismology (Gr. *seismos*, an earthquake; and *logos*, a discourse), and the instruments used in the study are known as seismographs and seismometers.

157. **Number and Distribution of Earthquakes.**—Earthquakes are of much more frequent occurrence than is usually supposed. Probably one occurs at least every week in some part of the world, but most of them are only slight shocks. The most violent earthquakes take place in volcanic regions, though some districts that suffer from these movements are free from volcanoes (see map). Still, it is certain that the two phenomena are connected, for the most violent earthquakes occur in the neighbourhood of volcanoes, and earthquake shocks often precede and accompany volcanic activity. It has also been noticed that a series of earthquakes in one district has stopped on the outbreak of a volcano in an adjoining district. The great earthquake region of the Old World is a district stretching from the Azores, along the northern shores and the islands of the Mediterranean, through Asia Minor to the Thian Shan Mountains. In the New World the western shores of South America are frequently visited by intense shocks. Among the Andes of Chili a shock of some kind is said to occur every few days. The Japanese islands are also frequently visited by earthquakes, and special attention is given to these phenomena at the Imperial College at Tokio. The earthquakes occurring in Britain are always slight. Nearly one-third of those known have taken place in the county of Perth. On April 22, 1884, an earthquake occurred in the neighbourhood of Colchester, which damaged some of the buildings.

158. **Causes of Earthquakes.**—It is not easy to assign the causes of earthquake action. Some of the slight tremors have been connected with variations of atmospheric pressure and with the attraction of the sun and moon, but it is plain that the more violent shocks arise from causes in the interior of the earth. Some of them may be consequences of the contraction of the earth's crust on cooling, by which great thicknesses of strata are broken and displaced; others may arise from the sudden generation and expansion of steam; while others may be the

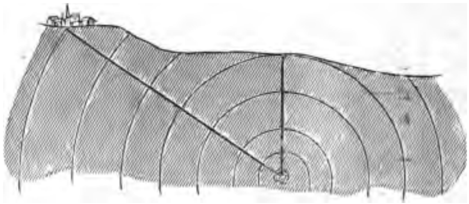


FIG. 137.—Diagram to illustrate propagation of earthquake-wave, and the mode of calculating the depth.

result of the falling in of immense cavities in the earth's crust. By observing the position of the place where the shock is vertical, and by ascertaining the angle at which the earth-wave reached the surface at other places, it has been found possible to determine the position of the place in the earth's crust where the shock originated. It is interesting to know that the depth of the point of origin is believed to be in all cases less than thirty miles.

159. **Effects of Earthquakes.**—We are very prone to imagine that earthquakes are among the mightiest forces affecting the surface of our earth. This is a mistake, for, although they often produce great destruction of life and great devastation among buildings, their permanent effects are often very slight. Yet at times large masses of rock and earth are displaced, changes of level are produced, and fissures formed in the surface of the ground. The coasts of Chili and New Zealand have several times been raised by earthquakes. At Cutch, on the delta of the Indus, an earthquake in 1819 produced a depression in one part and an elevation in another. The greatest effect is produced when the origin of the shock is beneath the bed of the sea. The earth-wave produced in the solid land causes huge sea-waves to form, and the distance to which these sea-waves extend is often very great. The sea-wave of the Iquique earthquake in 1877 was felt in all parts of the Pacific Ocean, from New Zealand in the south to the shores of Japan in the north. Much of the destruction produced at the great Lisbon earthquake in 1755 was owing to great sea-waves thirty to sixty feet high coming into the Tagus about an hour after the buildings of the town had been overthrown by the shaking of the ground. This earthquake was felt over the greater part of Europe, and even in North Africa. At first the water of the sea is usually seen to withdraw a considerable distance, and then a mighty inrush of large waves follows. The inhabitants of the western coast of South America know so well what this drawing back of the water means, that they take it as a warning, and often save their lives by escaping to the hills. In 1724 Lima was destroyed by an earthquake, and on the evening of the same day a mighty sea-wave eighty feet in height came over Callao. In August, 1878, a great part of Peru and Ecuador was devastated by an earthquake, and a great sea-wave overwhelmed Arica, every vessel in the harbour being either wrecked or carried far inland. The rate at which the great sea-waves caused by earthquakes travel has been used as a means of calculating the average depth of the ocean in which they occur.

160. **Slow Movements of Elevation and Subsidence.**—Besides the sudden changes of level produced by volcanic eruptions and earthquakes, there is a certain slow and quiet rise or sinking of the land over certain areas of the globe which takes place quite gradually and imperceptibly. These slow changes sometimes occur in volcanic districts, but they are also found in parts of the world where no volcanic or earthquake activity is known to have occurred.

161. **Signs and Proofs of Elevation.**—When land has been raised above the sea-level, it generally brings with it some evidence of having been once under water. On the south and west shores of the island of

Crete or Candia are seen the remains of docks and piers belonging to old Greek ports at an elevation of sixteen feet above the present sea level. On the Scandinavian peninsula in the Gulf of Bothnia marks were cut on the rocks by pilots in 1820, and these showed a rise of about four inches on being examined by Sir Charles Lyell in 1834. This shows an upward movement at the rate of about two and a half feet a century. But while the north of Scandinavia is slowly rising, the southern part is slowly subsiding. The evidence mentioned above refers only to historic times; but the existence of *marine shells* and *raised beaches* shows that these upward movements have been going on for vast ages. Parts of Tuscany and Sardinia have beds of shells at a height of 200 feet above the sea; while the harbours of Tunis are becoming too shallow for the approach of ships.

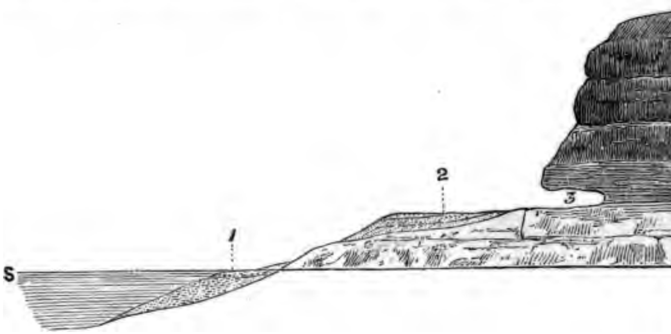


FIG. 138.—S, present sea-level at high tide. 1. Present sea-beach. 2. Old sea-beach. 3. Old sea-cave.

Raised sea-beaches afford very satisfactory evidence of upheaval. On every sea-shore where there is a range of rocky cliffs a beach of sand and shingle is formed by the action of the waves, and caves are often hollowed out of the rock. If the land be raised, both the beach and the cliff are lifted up beyond the region of the waves, and a new beach is formed at a lower level. This may then be raised, and a third beach formed at a still lower level. Such a series of raised beaches occurs in several of the Norwegian fiords, on some parts of the South American coast, and in other countries.

Raised beaches are also found on the southern and western shores of England and on some parts of the Scottish coasts. In some cases the old sea-caves, as on the coast of Kintyre, form a range of natural rock-hewn compartments at a level of ten to thirty feet above the present tidal limits, and are perhaps the most convincing of all the various evidences of ancient sea action.

162. **Signs and Proofs of Subsidence.**—When land has sunk below the sea level the surface disappears from view, and the proofs are not so plain as in the case of elevation. But there is the evidence derived from the disappearance of human erections, from the existence of submerged forests, and according to Mr. Darwin from coral islands. It has been stated that the south and west shores of the island of Crete are rising, but the existence of remains of old Greek towns beneath the surface of the water on the eastern shore shows that this part of the island is sinking. In the


MAP
Showing Coasts undergoing ELEVATION AND SUBSIDENCE and Distribution of Coral Islands and Reefs
Rising Land thus
Sinking
Coral Islands
ARCTIC OCEAN
NORTH AMERICA
SOUTH AMERICA
GREENLAND
Baffin Bay
Davis St.
Jan Mayen
Arctic Circle
Iceland
BRITISH ISLES
EUROPE
ASIA
AFRICA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
ANTARCTIC OCEAN
Tropic of Cancer
Tropic of Capricorn
Equator
Antarctic Circle
Aleutian Is.
Sandwich Is. (Hawaii)
Friendly Is.
Society Is.
Galapagos Is.
Bermudas
Bahama Is.
Azores Is.
Canary Is.
C. Verde Is.
Desert of Gobi
Tibet
Japan Is.
Philippine Islands
Caroline Is.
Solomon Is.
Fiji Is.
Lacadive
Maldive
Madagascar
Sumatra
Java
Crozet Is.
Kerguelen
Enderby Ld.
Wilkes Land
South Shetlands
100 Long. W. 80 of Green. 60
60 Long. E. 80 of Green. 100

southern part of Sweden the remains of houses, which were built of course above high-water level, are now buried beneath the water. The west coast of Greenland furnishes similar evidences of slow sinking. Submerged forests are found in some places where the land has slowly settled under favourable circumstances. These consist of stumps of trees still upright in the soil, often with beds of peaty matter, full of decaying roots, branches, and leaves. Such submerged forests are found on the coasts of Devon and Cornwall, and a large one exists near Hunstanton on the Norfolk coast.

CHAPTER XV.

THE ATMOSPHERE.

163. **The Atmosphere.**—Surrounding the crust of the earth on all sides, and reaching far above the summits of the mountains as well as filling the deepest cavities, there is a vast invisible ocean of gas or vapour which we call the air or atmosphere (Gr. *atmos*, vapour; *sphaira*, a sphere). This aeriform fluid is drawn towards the earth and kept from flying off into space by the force of terrestrial gravity, and it thus shares in all the movements of rotation and revolution of the solid globe. Animals and plants are sub-aerial beings, that is, they live beneath this air-ocean. It is the region in which many wonderful phenomena of nature take place—clouds, fog, rain, snow, hail, thunder, lightning, winds, and storms.

The composition of the atmosphere has been already set forth in par. 100, where we learnt that it is a mixture of nitrogen, oxygen, carbon dioxide, and very small amounts of other gases. There is always present water-vapour, but the amount varies greatly as will shortly be explained. These gases have different specific gravities, carbon dioxide being much heavier bulk for bulk than the others mentioned above. Yet, owing to the property of *diffusion* in gases, in consequence of which the molecules move freely and spread widely, there is complete intermingling of the gases in all regions, this intermingling being further aided by winds.

In recent years much attention has been directed to the *dust* or minute particles of solid matter, that are always present in the air, being kept suspended by the action of currents. These dust particles can be shown by sending a beam of sunlight or a lantern beam into any darkened space, for the track

of the beam is only rendered visible by reflection from thes particles. Ordinary dry air in the open contains about tw million dust-particles per cubic foot. They play an importan part in the condensation of the aqueous vapour of the air, as they act as nuclei around which the vapour condenses. Some of them are of organic origin, and provide the germs that lead to fermentation, mildew, or disease.

164. **The Water-vapour of the Air.**—The amount of water-vapour present in air varies considerably from day to day, but no matter how warm and dry the day is, there is always some present. This may be proved in the following ways. Bring into a warm room a tumbler full of ice-cold water. The oute surface, though perfectly dry, soon becomes bedimmed witl moisture. The reason is that the air near the cold glass be comes chilled, and as cold air cannot retain as much vapou as warm air, some of the vapour is condensed and deposite on the sides of the glass like dew. Another mod of proving that air always contains invisible wate vapour is to place some strong sulphuric acid a vessel and leave it for a time. This substan has the power of absorbing water, and after day or two we shall be able to see that tl quantity of liquid in the vessel has increas owing to the water-vapour absorbed into t sulphuric acid from the air.

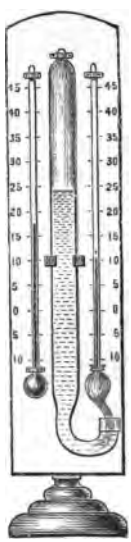


FIG. 139. —Wet-bulb hygrometer.

As already explained water is constan evaporating into the air, but the amount moisture that the air can contain before it saturated depends upon its temperature. Air a certain temperature is said to be saturat with moisture when it can hold no more, l the actual amount of water that a cubic foot air will contain varies from about 2 grains cubic foot at freezing-point to 12 grains per cu foot at 80° F. The important question, the fore, about the moisture or humidity of the is not, What is the actual amount of moist in the air? but, What is the amount of moisture in the

relative to the amount that it could contain at that temperature? We call the air "dry" when it is far from saturation, so that evaporation goes on freely; we call the air damp when it is near saturation, so that evaporation goes on slowly. Dry air in summer may actually contain more moisture than damp air on a cold winter day. The relative humidity of the air is often expressed as a fraction. Air is said to be "three-fourths saturated," for example, when it contains three-fourths of the water-vapour that it would hold at that temperature were saturation complete.

Hygrometers (Gr. *hugros*, moist; *metron*, a measure) are instruments for measuring the degree of moisture or relative humidity of the atmosphere. One of the most convenient is Mason's Dry and Wet Bulb Thermometer. Two similar thermometers are placed on a stand side by side, one of them having its bulb covered with muslin that is kept continually moist by its lower end dipping into a reservoir of water. The threads draw up the water by capillary attraction, and thus the muslin never becomes dry. This moistened muslin is constantly losing its water by evaporation, and the dryer the air the greater is the rate of evaporation. But as a liquid evaporates heat is absorbed, and this reduces the temperature of the wet bulb. The dryer the air the more rapid will be the evaporation and the greater the difference of temperature shown by the two thermometers. Unless the air is saturated with moisture, the wet bulb always indicates a lower temperature than the dry bulb. From this difference, by means of tables, we can calculate the degree of humidity of the air, the quantity of vapour in a certain volume of air, and the *dew-point*, or temperature of saturation. In the figure the thermometers are Centigrade thermometers, and the wet bulb indicates a temperature of 12° C. (= 53·6 F.), while the dry bulb indicates 17° C. (= 62·6 F.).

165. **Height of Atmosphere.**—Since air, like all gases, is highly compressible, it is evident that its densest layers are close to the earth, and that it gets rarer and rarer the higher we ascend. At a height of about seven miles it is too thin to sustain life; at about 50 miles high it is not dense enough to reflect the sun's rays, for twilight effects cease at that height.

Yet we have proof that it extends even beyond this, for meteors or shooting-stars have been found to be visible at a height of 200 to 300 miles, and this could only be because they had become ignited owing to the friction caused by their rapid passage through the air. These meteors are comparatively small masses of matter which, passing into our atmosphere, either become heated so intensely as to disappear in

a train of blazing gas, or fall on to the earth as aërolites or meteorites. Specimens have been picked up, and on examination they are found to consist of the same elements as exist on our earth, native iron being nearly always the chief ingredient.

166. **Air possesses Weight.**—Since air is matter, and all matter on or near the surface of the earth is subject to the earth's attraction, *i.e.* to gravity, air must have weight in consequence of this downward pull to the earth's centre (par. 14). A flask, therefore, from which air has been removed, must weigh less than it does when it is said to be "empty," though in reality full of air. A flask provided with a screw-tube and stop-cock, fitting air-tight through the cork, can have its air drawn out by means of an air-pump. If we weigh such a flask exhausted of air, and then open the stop-cock, air is heard rushing in, and the flask increases in weight. Careful experiments show that at the sea-level a cubic foot of air weighs about $1\frac{1}{5}$ oz., or, using the metric system, a litre of air weighs about $1\frac{1}{3}$ grams. From these figures it would be easy to calculate the weight of air in a room or other space, having the length, breadth, and height supplied.

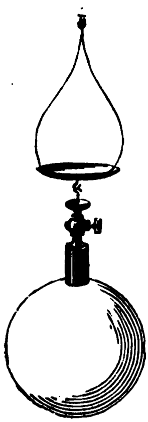


FIG. 140.—Flask exhausted of air.

167. **Pressure of the Atmosphere.**—Since air has weight it will exert a downward pressure on everything upon which it rests. But gravity not only causes downward pressure in fluids, but it also causes all fluids to exert pressure in all directions. A solid transmits pressure only in the direction in which the force is acting, but air, like other fluids, transmits pressure downward, sideways at every angle, and vertically upwards. We will now make some experiments to illustrate the pressure of the atmosphere.

Experiment 96.—Take a boy's leather sucker and press the wet undersurface closely against a smooth stone or a small piece of marble slab. The two now refuse to part, and the stone can be raised. This is because nearly all the air having been expelled from below the sucker, the pressure of the atmosphere can only act on the upper surface, the close-fitting disc of

keeping the air from getting to the under surface. This illustrates wnward pressure of the atmosphere. But the sucker may also be

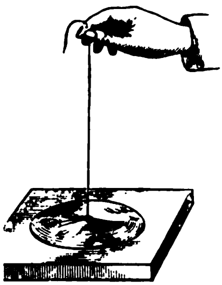


FIG. 141.

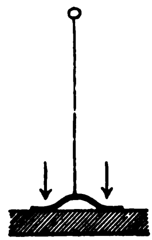
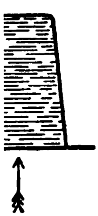


FIG. 142.

ɔ adhere to the window pane or the ceiling in the ay, so that the air must press sideways and upwards as downwards. (Instead of a leather sucker we may indiarubber disc like those used to support objects ɔ windows.) A pinhole through the sucker will let ıtmospheric pressure to the other side, and the two en part. It should be noted that the "sucker" ɔt really *suck* or draw the stone, for the adhesion wo surfaces is due to atmospheric pressure.

periment 97.—Take a tumbler, fill it with water, heet of paper over the mouth, and, holding the paper in position with the hand, invert the tumbler. The water remains in the vessel. What keeps the liquid up? Not the paper, but the upward pressure of the atmosphere. The paper serves to transmit this pressure in an effective way. On making a hole through the paper, the atmospheric pressure gets to the other side, counteracts the upward pressure, and the liquid then falls by its own weight.



G. 143.

Repeat the experiment, using less tumblerful, and the water will still remain up as the pressure of the atmosphere is kept from getting ɔther side of the paper, for the upward pressure of nosphere is greater than the downward pressure of ter and of the air left in the tumbler.

periment 98.—Take a narrow glass tube about two ng, and open at both ends. Place it upright with l in a vessel of water and apply the mouth to the end. On drawing air out of the tube the water eing forced up by the pressure of the atmosphere surface of the water in the vessel. This atmo- pressure on the surface is transmitted through *ter in all directions* as indicated by the arrows in

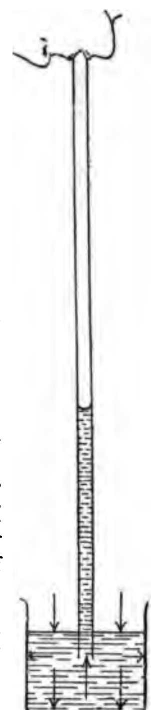


FIG. 144.

the figure. Hence this experiment illustrates not only the pressure of the atmosphere, but the transmission of pressure through a liquid to the bottom, the sides, and upwards. If all the air be drawn outside the tube by the mouth, the water will rise to the top, and it may be drunk. The experiment explains what occurs when liquids are "sucked" by means of a straw.

FIG. 145.

Experiment 99.—Take a common glass syringe and examine its action during the raising of water and when squirting it out. The instrument consists of a cylindrical tube in which a disc fitted to a rod and called the movable piston fits air-tight. The lower end of the tube terminating in a conical nozzle, at the end of which is a small hole. A careful study of its action will not only further illustrate the action of atmospheric pressure, but enable us to understand the working of a common pump.

Begin by seeing that the piston moves up and down freely when the syringe is held in the air, and notice that while the piston is being forced down air can be felt passing out. When, therefore (Fig. 146), the syringe A has had its piston pushed to the bottom B, there is only a small quantity of air left in the conical part of the syringe B. Put the nozzle into water and then pull the piston up, and we have the condition represented at C, for the water is forced up by the outside pressure of the atmosphere, which is much greater than the pressure exerted by the small quantity of air that remains in the syringe. The water remains in the syringe when it is taken out of the vessel, the outside atmospheric pressure keeping it in as at D.

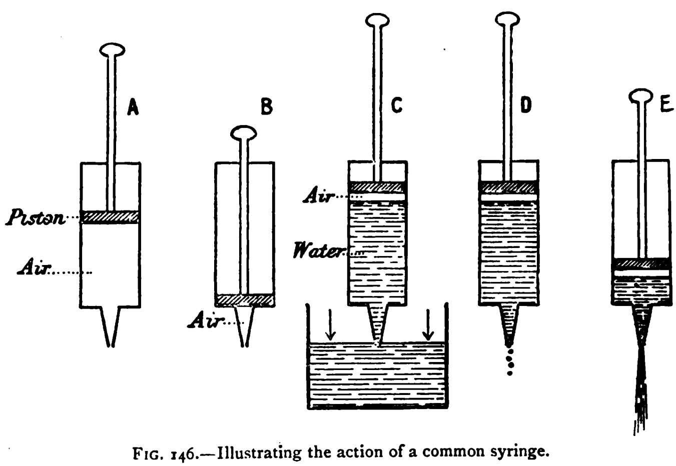


FIG. 146.—Illustrating the action of a common syringe.

Now press the piston downwards so that your pressure, plus the small pressure of the air included, is greater than the outside atmospheric pressure, and the water is then expelled from the syringe as at E.

168. The Common Suction-pump.—The action of the common pump by which water is raised from wells, etc., will now present no difficulty. As in the syringe there is a piston working in a barrel MN (Fig. 147). There are two lids or valves, one in the piston F, and one at the bottom of the barrel, both valves opening upwards only. A pipe called the suction-tube, N*e*, leads from the barrel to the well. The mode of action is as follows:—

Push the piston down to the bottom of the barrel. This will tend to compress the air below, V will close, and F open to let the air get out above the piston-valve. On raising the piston its valve falls down, and the air in ND will expand, open the valve V, and follow the piston. The pressure of the air within the suction-tube being diminished, the external atmospheric pressure, HH, will cause the water to rise some distance in *e*N. On causing the piston to descend again V again closes, and more of the air in the barrel passes upwards through the piston-valve, while on raising the piston again the pressure of the air left in the suction-tube again lifts the valve V, and more air rises into the barrel. Pressure in the suction-tube being thus again diminished, the outside air-pressure forces the water still higher in the suction-tube. The action continues until the water reaches V, and if V is less than 30 feet above the well, the air-pressure will push the water through V into the wide barrel. On bringing down the piston then, it will shut the valve V, while at the same time the water will be forced through the valve F and get above the piston. On next raising the piston F closes, and we shall lift up the water that has passed through the piston-valve, and this will flow out at the side spout of the barrel.

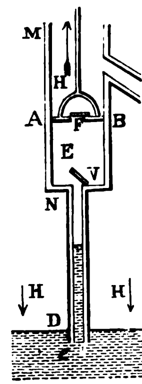


FIG. 147.

169. The Barometer.—We are now prepared to understand the construction and use of a barometer—the instrument used for *measuring* the pressure of the atmosphere.

Experiment 100.—Take a glass tube about 33 inches long, closed at one end and open at the other, fill this tube quite full with mercury, and, closing the open end with the thumb, invert it in a cup or cistern of mercury so that the open end dips beneath the surface. You will then see the mercury in the tube fall for a short distance, but a column, the top of which is about 30 inches in perpendicular height from the surface of the mercury in the cistern, remains in the tube. An Italian philosopher called Torricelli was the first to make and reason upon this experiment in 1643. He argued quite correctly that the column of mercury was supported in the tube by the external pressure of the atmosphere on the surface of the mercury in the basin, this pressure being transmitted through the mercury in the basin to the under surface of the mercury in the tube. But the tube being closed above, there is *no* pressure at the top, and the space above the *mercury in the tube is quite* empty, and is known as the *Torricellian* vacuum.

Were a hole made through the closed end at the top of the t upward pressure of the air through the liquid in the basin woul counterbalanced by the downward pressure of the air at the t mercury would then fall by its own weight. Since the pressur atmosphere just balances a column of mercury 40 inches high, i that if we can find the weight of this mercury column we shall l weight of a column of air standing on a base of the same reaching to the top of the atmosphere. It is found that a co mercury in a tube having a sectional area of one square inch and a 30 inches weighs about 15 lbs. Hence, as before stated, the w pressure of the atmosphere is 1 lbs. on every square inch. A *b* then, in its simplest form, con tube dipped into a cistern of and containing a column of th supported by the atmospheric which it serves to measure.

FIG. 148.—Filling the barometer-tube.

By the *height* of the ba is meant the perpendicu tance between the two s

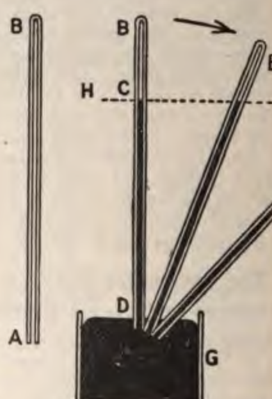


FIG. 149.—The inclination of the tube does not alter the vertic the mercury.

of mercury, that in the tube and that in the cistern. barometer tube be inclined, the mercury will rise hi the tube, but the perpendicular distance between surfaces will not be altered.

It will be useful for the student to remember that *call a pressure* of 15 lbs. per square inch a pressure

atmosphere, or a pressure of 30 inches of mercury. A pressure of two atmospheres would therefore mean a pressure of 30 lbs. per square inch, or a pressure of 60 inches of mercury.

170. **Different Forms of Barometer.**—The simplest form of mercurial barometer is the Cistern Barometer, illustrated in Fig. 148, with the addition of a scale of inches and parts of an inch placed beside the glass tube. If this scale be laid off from a zero point at some fixed line on the wall of the cistern, a difficulty arises, since during changes in the length of the mercury column in the tube, changes of level occur in the cistern also. To overcome this difficulty, we may (1) disregard any zero point and find the height of the mercury column by finding the difference between the level of the mercury in the cistern and in the tube; (2) graduate a scale, as in the Kew barometers, which will allow for the change of level in the cistern; (3) arrange, as in the Fortin barometer, a cistern with a pliable base of leather that can be raised or lowered by means of a screw, *c*, to a fixed zero point, *a*, in the cistern (Fig. 150). The graduation on the scale always expresses the true height above the zero point. The upper part of the cistern in a Fortin's barometer is made of glass, and the zero point is the top of a fixed piece of ivory, *d*, that hangs down into the cistern. Before reading the instrument the upper surface of the mercury in the cistern is made to correspond exactly with the point of this ivory. The whole instrument may then be enclosed in a case.

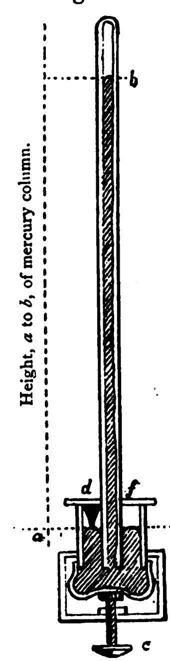


FIG. 150. — Diagram showing a Fortin's barometer.

In the Siphon Barometer there is no cistern, but a U-shaped tube with one arm much longer than the other, the longer arm being closed at the top. The short expanded open arm serves as the cistern, and the reading of this barometer is the difference of level of the mercury in the two arms. In Fig. 151, for example, a height of 29 inches is indicated. Fractions of an inch (tenths) *are usually indicated* on a scale.

The ordinary wheel barometer is a modification of the siphon barometer. A small weight floats on the surface of the mercury in the short open limb, and this weight is connected, by a string passing over a wheel or pulley, with a rather less weight. When the mercury rises or falls in the barometer the weight rises or falls, and in so doing turns the pulley wheel. To the axis of the pulley wheel an index is attached, and this moves over a dial-plate, on which figures and descriptions are written indicating the height of the mercury and the kind of weather to be expected.

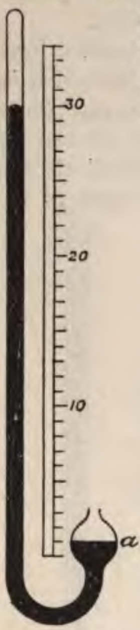


FIG. 151.—Siphon barometer, with scale of inches.

FIG. 152.

In the Aneroid Barometer (Gr. *a*, not; *neros*, moist) the pressure of the atmosphere is measured without using mercury or any other liquid. This consists of a cylindrical metal box exhausted of air. The flat top and bottom of the box are corrugated in concentric rings, and supported by a pillar in the centre attached to a spring above. Increases of atmospheric pressure pulls the spring down; diminution of pressure raises it. The movements of the spring are intensified by a lever, and carried by a rack and pinion to an index finger that moves over a dial-plate. Variations of atmospheric pressure are thus recorded, and, by the help of a mercurial barometer, the dial-plate is graduated to indicate the pressure in inches and fractions of an inch.

171. **Advantages of Mercury for Barometers.**—Mercury is generally used for barometers in preference to other liquids because it is the heaviest of all liquids, and the height of the column is therefore small and more easily observed. It is also used because it does not wet the glass, and because it does not evaporate from the cistern. If water were used, the *water barometer* would be nearly 34 feet high when the mercurial column stood at 30 inches; for the specific gravity of mercury is 13·5, that of water being 1; and 30 inches multiplied by 13·5 is nearly 34 feet. *Glycerine*, however, is sometimes used. The length of its column is rather more than ten times that of mercury, and hence small alterations of atmospheric pressure cause larger and more distinct

changes in the level of the tube than in the mercurial barometer.

172. **Boyle's Law.**—Boyle's law states the relation between the volume and the pressure of a gas, and this relation is of great importance. It has already been stated that air and other gases are highly compressible fluids, and that when we compress a gas into a smaller space we increase its expansive force, *i.e.* its elasticity; now if a cylindrical vessel full of air or other gas at the ordinary pressure of the atmosphere be fitted with a piston we can, by pressure, force the particles of gas into less room. Calling the original atmospheric pressure P, we can, by doubling this pressure, squeeze the air into half its original volume. In so doing we have doubled the density of the gas, and also doubled the internal expansive force or elasticity of the gas, for the imprisoned gas has now sufficient elasticity to balance two atmospheres, 2 P. A further increase of external pressure gives a further increase of density, and when the pressure has been increased three times (to 3 P) we find that the volume has been reduced to one-third while the density has been trebled. Boyle's Law therefore states—

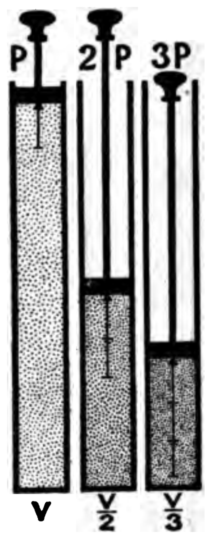


FIG. 153.—Illustration of the relation between pressure, volume, and density in gases.

The volume of a gas varies (or changes) inversely as the pressure when the temperature remains constant.

Hence when we *double* the pressure on a gas, we reduce its volume to *one-half;* when we *treble* the pressure, we reduce the *volume* to *one-third;* and so on.

Since air and other gases become warmer when compressed, it is important that the gas should be kept at the same temperature during experiments on the relation between pressure and volume.

It follows, from the above statement of Boyle's Law, that—

The density of a gas varies directly as the pressure to which it is subjected.

Hence if we *double* the pressure, we also *double* the density, and if we *treble* the pressure, we *treble* the density; and so on. Increase of density is proportional to increase of pressure, and decrease of density to decrease of pressure. As the pressure of the atmosphere at any point is due to the overlying air, it is evident that its pressure must diminish as we ascend above the earth's surface, and with this decrease of pressure there will be a decrease of density at the same rate.

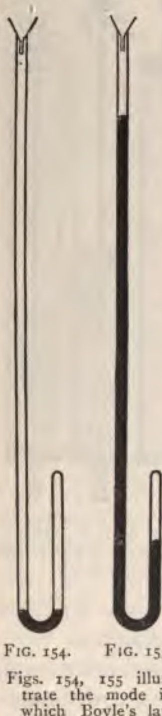


FIG. 154. FIG. 155.

Figs. 154, 155 illustrate the mode in which Boyle's law can be proved for pressures greater than one atmosphere.

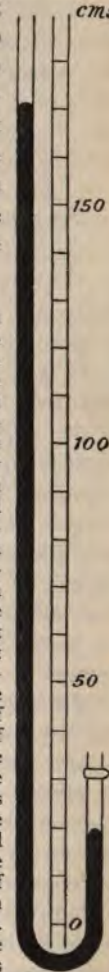


FIG. 156.

Experiment 101.—To verify Boyle's Law, obtain a glass tube of uniform bore bent into the form of a U, but with one arm much longer than the other. The short arm being closed at the top, and the long arm open, first pour in a little mercury at the open end so as to fill the bend. By inclining the tube the mercury can be got to the same level in both limbs. We have then some air imprisoned in the shorter limb, and it is at the pressure of the atmosphere, since the level in the two limbs is the same—the atmospheric pressure being transmitted down the long open limb. Now pour more mercury into the long branch, giving it time to recover its temperature, and it will be noted that the enclosed air diminishes in volume owing to the increase of pressure produced. The increase of pressure is measured by the difference of level of the two mercury columns; the diminution of volume is measured by the decrease in the length of enclosed air, as the tube is uniform in bore. When the volume of enclosed air has been reduced to one-half, it will be found that the increase of pressure is about 30 inches of mercury, as this will be the difference in level of the two columns of mercury. This is equal to an additional pressure of one atmosphere, *i.e.* two atmospheres of pressure altogether. (If the barometer stand at 29 inches, 29 inches will represent another atmospheric pressure.) When the volume has been reduced to

one-third, the difference of level will be about 60 inches, and the total pressure three atmospheres.

In Fig. 156, a scale of centimetres is placed beside the tube. The mercury in the shorter tube is at a height of 20 cm. and in the longer tube at a height of 170 cm., so that the difference is 150 cm. Taking the atmospheric pressure at the time as 75 cm., the total pressure on the enclosed air is 220 cms., or three atmospheres, and the gas therefore has been reduced to one-third its original volume.

We again arrive at the result—*The volume of a gas is inversely proportional to the pressure upon it.* The law is true, not only for pressures greater than the atmosphere, but for pressures less than the atmosphere. If we diminish the pressure the volume increases in the same proportion, just as when we increase the pressure the volume diminishes in the same proportion.

173. **Density and Pressure of the Atmosphere at Different Heights.**—The pressure of the air decreases gradually as we ascend above the sea level. That this is so will be plain when we consider that as we ascend the superincumbent mass diminishes; the higher we go the thinner becomes the layer of air above us. But, in consequence of the law that the volume of a gas is inversely proportional to the pressure to which it is subject, the density of the air diminishes as well as the pressure. If we imagine the atmosphere divided into layers, the more compact layers will be at the bottom, just as in a stack of hay. On the summit of Mont Blanc, 15,000 feet high, the barometer only indicates about 15 inches pressure, and hence the air there is only one-half as dense as it is at the level of the sea, its particles being at twice the distance. In other words, a given weight of air will occupy twice the volume that the same weight occupies at the sea level. Hence at great heights animal life cannot be supported. As the barometer falls the higher we ascend, it is plain that if we knew the law by which this fall takes place, we could ascertain the height of a mountain by means of the instrument. The law is rather complicated, but for small elevations a fall of 1 inch in the barometer indicates a height of 900 feet. A better, but still only an approximate rule is, "Observe the

heights of the barometer at the bottom and at the top mountain; divide the ence of the heights sum, and multiply th by 52,428: this will height of the moun feet." The use of th meter to measure he often of great advan travellers.[1]

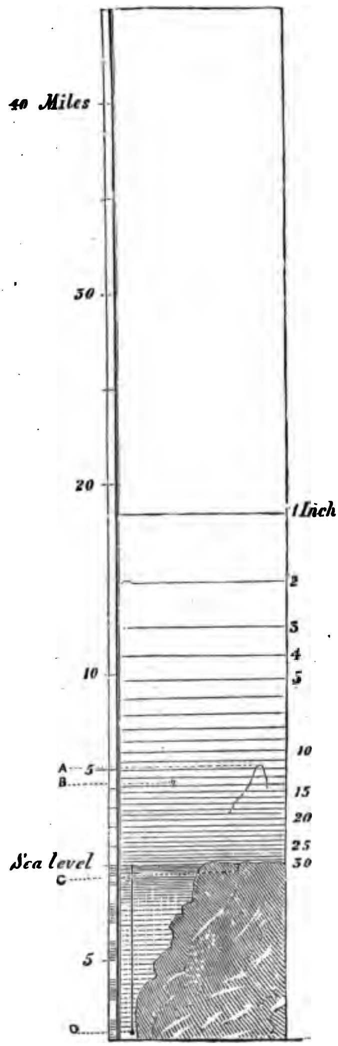


FIG. 157.—Section of atmosphere.

The diagram repr natural section of th sphere. On the left i the height in miles ab sea level, while on th is shown the corres heights of the barom inches. A indicat highest peak in the H Mountains (29,000 fe the height (23,019 f tained by Gay Lussa balloon in 1804 (Mr. (and Mr. Coxwell rea height of 37,000 feet, miles, in 1862); C, D mine, in Cornwall, 15 (the deepest mine is n feet); D, a depth of 1 miles. But no such has really been fou deepest reliable s being up to the prese 28,000 feet, or ne miles, off the coast of

[1] Mr. Whymper's b gave a reading of 14·1 i the summit of Chimborazo, 20,500 feet high.

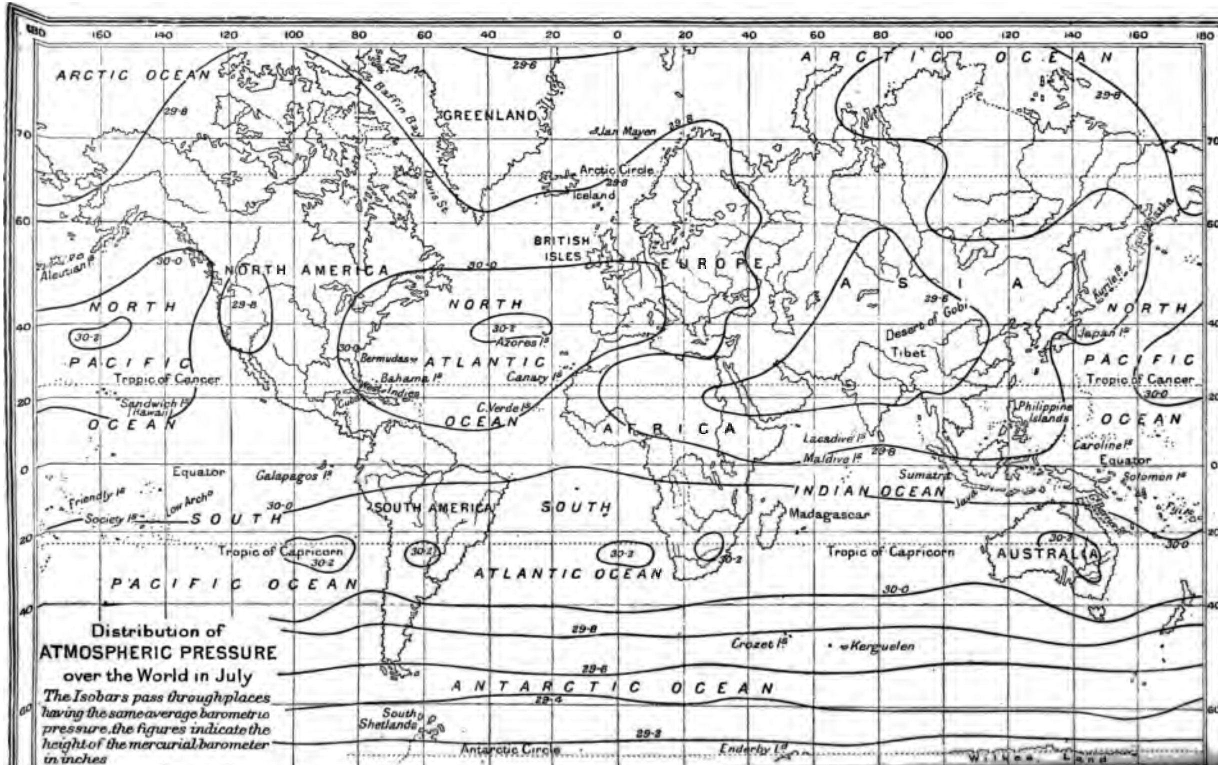
174. **Variations of Barometric Pressure.**—Not only does the pressure of the atmosphere vary at different heights, but it varies at the same level at different places on the earth, and also at the same place at different times. The two chief causes of this variation are—(1) the varying temperature of the air; (2) the varying quantity of aqueous vapour in the air. It is a general rule that the barometer usually falls when the thermometer rises, and the barometer usually rises when the thermometer falls. The heat that causes the thermometer to rise expands the air, which consequently overflows into the neighbouring regions; and the pressure of the atmosphere being thus diminished, the barometer falls. On the other hand, when the thermometer falls, owing to a diminution of temperature, the air contracts, and this produces an influx from the neighbouring regions, and consequently an increase of pressure and a rise of the barometer. This influx of air is generally accompanied by descending currents, while an expansion of the air causes ascending currents. Thus where there are descending currents in the atmosphere the pressure will increase, and where there are ascending currents in the atmosphere the pressure will decrease. Remembering that, generally speaking, the heating power of the sun's rays is greatest at the equator and decreases towards the poles, we may expect that the heated air near the equator expands, rises, and overflows, and that therefore the pressure will be less at the equator than in higher latitudes. But, owing to the spherical form of the earth, the air flowing towards the poles moves into a region becoming narrower and narrower, and is at last brought down to the surface of the earth at about the 30th parallel of latitude. Here we find a region of high pressure on both sides of the equator. The air is chiefly heated, as we shall presently show, by contact with the surface of the globe; and as the heating effects of the sun's rays on land and water are very different, variations of temperature, and therefore of pressure, in a district depend to some extent on whether the surface is land or water. The other chief cause of differences in barometric pressure is due to the varying quantity of water vapour in different places, and even in the same places from day to day.[1] Water vapour is much lighter than air, and the addition of a considerable quantity of vapour lessens the pressure of the atmosphere, and causes the barometer to fall, the mixture of air and vapour being lighter than dry air. In regions like the Antarctic Circle, where there is a large quantity of vapour, the barometer stands low; but in almost every region the quantity is nearly always changing, sometimes increasing from great evaporation, sometimes diminishing from being condensed into rain, hail, or snow. A fuller account of the regions of high and low pressure is contained in the "Advanced Physiography."

175. Mr. R. H. Scott gives the following statements from Professor Mohn's "Treatise on Meteorology":—

The barometer stands high—

(1) When the air is very cold, for then the lower strata are denser and more contracted than when it is warm.

[1] Between the tropics the diurnal variation amounts to one-tenth of an inch, there being two highest and lowest points at regular periods of the day. In the temperate zones the diurnal variation is less, and not easily observed *owing to its occurrence* in conjunction with accidental variations.



Distribution of ATMOSPHERIC PRESSURE over the World in July

The Isobars pass through places having the same average barometric pressure, the figures indicate the height of the mercurial barometer in inches

(2) When the air is dry, for then it is denser than when it is moist.

(3) When in any way an upper current sets in towards a given area, for this compresses the strata underneath.

Conversely, the barometer stands low—

(1) When the lower strata are heated, causing the surfaces of equal pressure to rise and the upper layers to slide off, as already described, for by this means the mass of air pressing on each unit of area below is reduced.

(2) When the air is damp, for as the density of aqueous vapour at the temperature of 60° and pressure of 30 in. = 0·622, air being = 1, the mixture is lighter the more vapour it contains, and consequently damp air does not press so heavily as dry on the unit of area below.

(3) When the air from any cause has an upward movement, for this of course acts in the same manner as (1).

176. **Isobars** (Gr. *isos*, equal; *baros*, weight).—Isobars are lines drawn through places having an equal barometric pressure during a certain period. They may be drawn for each month or season, or for the whole year. These isobars are usually drawn at differences of $\frac{1}{10}$ of an inch. In the *Times* newspaper there is each day a chart of North-western Europe, on which the isobars, the temperature, and the direction and force of the wind are shown for the previous day. On the accompanying map are drawn isobars through those places having the same average pressure during the month of July. If we were to compare it with one for January we should easily see how the pressure is affected in some districts by the season of the year (being usually less in summer than in winter), and how the land and water cause local differences of pressure.

Thus in January we find a pressure of nearly one inch more in Central Asia than we do during the great heat of July, while over the oceans generally, except in the higher northern latitudes, the pressure is more regular during the year than over the land. Taking the surface of the globe as a whole, we find that there are two belts of high pressure passing round the globe, one on each side of the equator. Between these two lies a *belt of low pressure* in the tropical regions, the lowest

mean pressure of this belt being near the equator. Two oth(regions of low pressure surround the poles, the one round tł north pole being divided into two centres.

177. **Relation of Barometric Variations to the State of the Weather.**- In Ganot's "Treatise on Physics," as edited by Professor Atkinson, th following remarks are made under this head :—

"It has been observed that, in our climate, the barometer in fin weather is generally above 30 inches, and is below this point when ther is rain, snow, wind, or storm ; and also that for any given number of day at which the barometer stands at 30 inches there are as many fine as rain days. From this coincidence between the height of the barometer and th state of the weather the following indications have been marked on th barometer, counting by thirds of an inch above and below 30 inches :—

Height	State of the Weather
31	Very dry
$30\frac{2}{3}$	Settled weather
$30\frac{1}{3}$	Fine weather
30	Variable
$29\frac{2}{3}$	Rain or wind
$29\frac{1}{3}$	Much rain
29	Storm

"In using the barometer as an indicator of the state of the weather w must not forget that it really only serves to measure the weight of th atmosphere, and that it only rises or falls as the weight increases c diminishes ; and although a change of weather frequently coincides with change in the pressure, they are not necessarily connected. This coinc dence arises from meteorological conditions peculiar to our climate, an does not occur everywhere. That a fall in the barometer usually precede rain in our latitudes is caused by the position of Europe. The prevailin winds here are the south-west and north-east. The former, coming to u from the equatorial regions, are warmer and lighter. They often, there fore, blow for hours or even days in the higher regions of the atmospher before manifesting themselves on the surface of the earth. The air i therefore lighter, and the pressure lower. Hence a fall of the baromete is a probable indication of the south-west winds which gradually exten downwards, and reaching us after having traversed large tracts of water are charged with moisture and bring us rain.

"The north-east wind blows simultaneously above and below, but th hindrances to the motion of the current on the earth by hills, forests, an houses cause the upward current to be somewhat in advance of the lowe ones, though not so much so as the south-west wind. The air is therefor somewhat heavier even before we perceive the north-east, and a rise of th barometer affords a forecast of the occurrence of this wind, which, as i reaches us after having passed over the immense dry tracts of land i Central and Northern Europe, is mostly dry and fine. When the baromete rises or sinks slowly, that is, for two or three days, towards fine weather o towards rain, it has been found from a great number of observations tha the indications are then extremely probable. Sudden variations in eithe directions indicate bad weather or wind."

178. **Corrections of the Barometer.**—In making accurate observation *corrections* have to be applied to the barometer—(1) for the height of th

observing station above the sea-level; (2) for temperature. In order to compare barometric indications taken at different places, it is necessary to reduce them to a common height, and the sea-level is taken as the standard height. The higher the place is above the sea-level the lower will be the reading of the barometer. The rule applicable to the estimation of heights already referred to is made use of for this purpose. The correction for temperature is necessary because the mercury expands and contracts for differences of temperature, and hence different atmospheric pressures might indicate the same height if the temperature varied. Hence barometers usually have a thermometer attached in order to show the temperature at the time of observation. The rule often given is, "Deduct the ten-thousandth part of the observed height for each degree of Fahrenheit above 32°." All observations are thus reduced to a common temperature.

179. **Temperature of the Air.**—*How the Air is heated.*—We have already explained in par. 52 how the temperature of the air is ascertained by means of the thermometer, and we have now to explain how the air is heated and in what way its

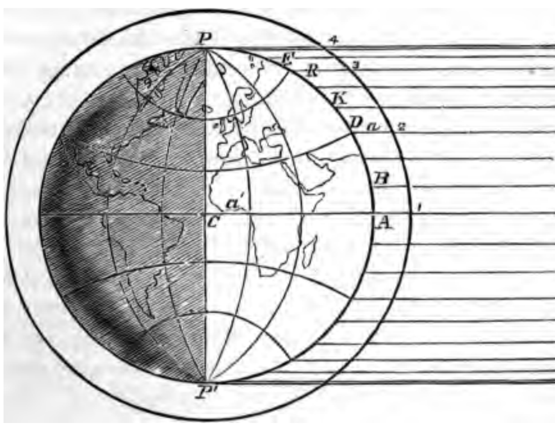


FIG. 158.

temperature varies. The earth receives nearly the whole of its yearly supply of heat from the rays of the sun, the supply that comes from the interior being inappreciable at the surface. Dr. Haughton says, "The heat received from the interior of the earth at present is sufficient to melt a layer of ice one quarter of an inch in thickness all over the surface of the globe; while that received from the sun would melt a layer 46 feet in thickness, being thus 2208 times greater than the heat

derived from the interior." If there were not water-vapour i the atmosphere the rays of heat from the sun would pas through it without suffering loss, and a great portion of wha reached the earth would then be absorbed by the rocks an soil covering its surface. But, as the air always contains mor or less aqueous vapour, there is a certain quantity of the sun's rays absorbed by the atmosphere, and the greater the distance of air through which the sun's rays pass, and the richer the strata of air are in this water-vapour, the greater is the numbe of the sun's rays that are absorbed. As the rays of the su pass through a much larger thickness of air in the morning an at night than during the middle of the day, the amount of hea that reaches the earth is made less at these times than at noor Hence the greater warmth of the sun's rays at midday. It ha been estimated that in this way a vertical beam loses abou 20 per cent. of its heating power, and that in the morning c evening the loss is nearly 95 per cent. The average loss i our latitudes is nearly 50 per cent.

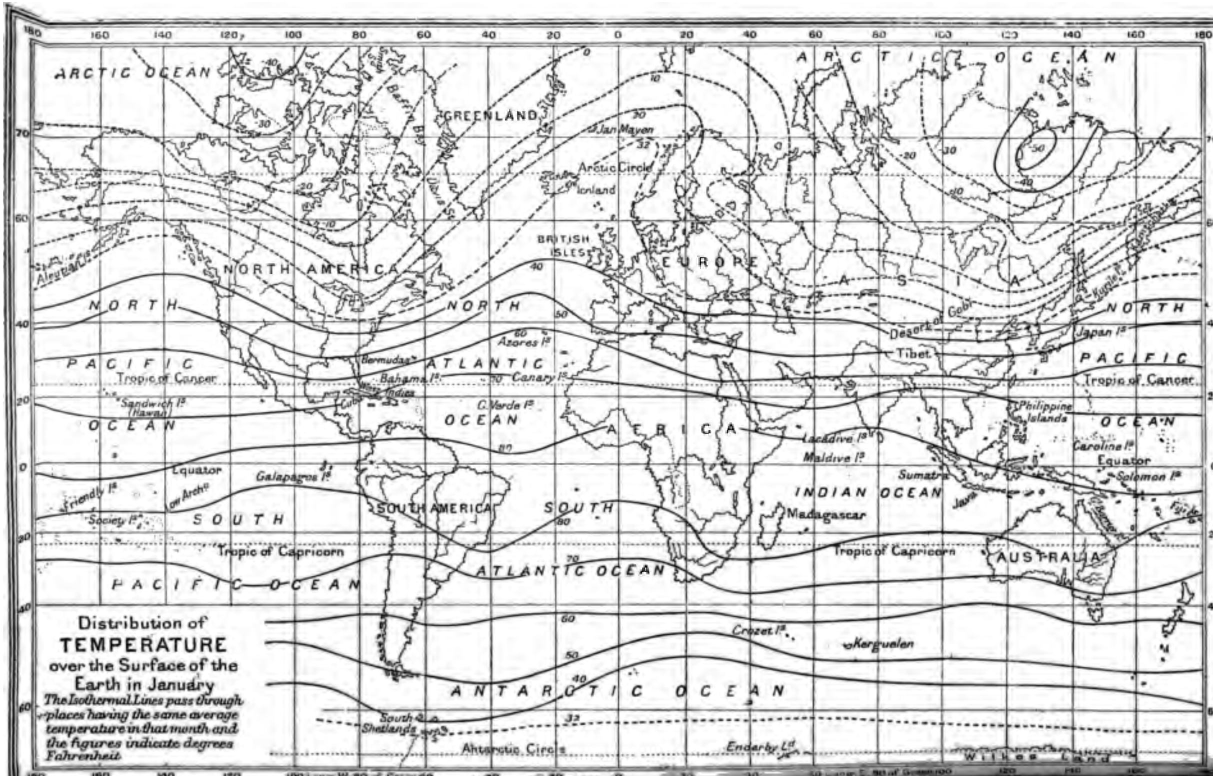
There is also another reason why it is warmer at noon tha in the morning or evening. If we imagine a cylindrical bea of rays of a certain size striking the earth, we shall easily se that when these rays come perpendicularly they fall on a muc less surface than when they fall obliquely (Fig. 158). Th heating power of such a beam is concentrated on a smaller are the more nearly vertical the beam is. For similar reasons it warmer near the equator than near the poles. Fig. 158 repr sents the earth, the axis being in the position with regard t the sun that it has on March 21 and September 23. The su is supposed to be at an immense distance to the right, and h rays are represented as coming in parallel lines towards th earth. The half meridian circle is divided into 18 equal par of 10° each, 9 parts being included between A and P. It easy to see that the rays strike the earth more obliquely as the approach the pole. If we suppose each pair of lines to repr sent a bundle of rays, we see that each of these bundl becomes narrower towards the poles, and that, therefore, eac of the equal strips of 10° gets a smaller quantity of light an heat as we leave the equator. The outer circle represents th

atmosphere, and here also we see how the distance of the ray through the atmosphere increases as we approach the poles. For 1A is shorter than 2D, still shorter than 3E, and still shorter again than 4P.

Of those rays that reach the surface we find that some are reflected or thrown back, but that they are mostly absorbed by the ground and then slowly radiated back. Both the rays that are reflected and those that are absorbed heat the air; for these rays are rays of dark heat, unlike the sun's luminous rays, and can be absorbed in great part by the overlying atmosphere. As is now well known, the presence of water-vapour in the atmosphere greatly checks radiation from the earth, the moisture acting as a screen or covering spread over the earth, allowing the luminous rays from an intensely heated source like the sun to pass through rather freely, but restraining the non-luminous rays from a source of lower temperature like the heated earth. Gradually, however, the warmth passes from the lower into the upper atmospheric strata, and is then lost by radiation into the intensely cold regions of space, the loss being about equal to what is received.

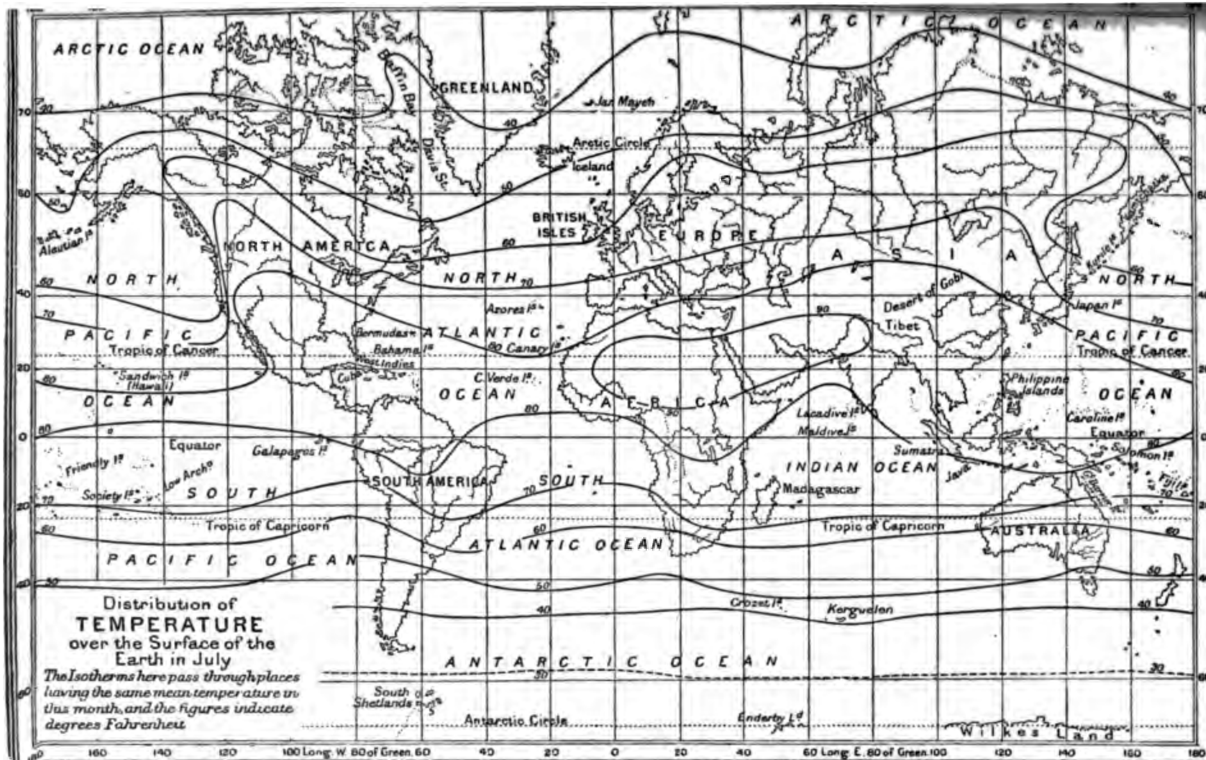
180. *Mean Temperatures.*—The average temperature of the day may be found by taking the temperature every hour and dividing by twenty-four, though it is generally sufficient to take only two observations, one at 9 A.M. and one at 9 P.M., and divide by two. The average temperature for any month may be obtained by dividing the sum of the daily averages by the number of days in the month, and the yearly average by dividing the sum of the monthly average by twelve. The hottest part of a clear day, as shown by the shade thermometer, is usually about two o'clock in the afternoon, and the coldest part is in the early morning about four o'clock. The hottest period of the year in the Northern Hemisphere is towards the end of July, for during the summer the heat has been accumulating owing to the amount of heat received from the sun being then greater than that lost by radiation.

181. *The Temperature depends on Latitude.*—From what has just been said, and from the fact that the solar rays are nearly vertical at and near the equator, we see that the equatorial belt of the globe will have the highest temperature, and that, generally speaking, the further we go from the equator the colder will it become, the angle at which the solar rays strike the earth diminishing as we pass towards the poles (Fig. 158). If, then, there were no other cause, we should have a regular diminution of temperature from the equator to the poles, and every place in the same latitude would have the same temperature. But we know that this is not the case, even at the same height above the sea-level. When we examine a chart of the world on which isotherms (Gr. *isos*, equal; *thermos*, heat) are drawn through places having the same temperature of the air during a



Distribution of
TEMPERATURE
over the Surface of the
Earth in January

The Isothermal Lines pass through places having the same average temperature in that month and the figures indicate degrees Fahrenheit



Thermal Lines at 32° and below are shown by pecked lines.

MAP V.

given period, we see that these lines are very irregular and vary considerabl at different seasons, especially over continental areas. On referring to th maps on which the isothermal lines are drawn for January and July, it wi be seen how very irregular these lines are in the Northern Hemisphere, an how comparatively regular they are in the Southern Hemisphere, wher there is a great preponderance of water. These lines thus show that tem perature depends more on latitude in the great oceanic areas of the glob than in the continental areas, or in the regions where the sea and lan come together. As a rule, the Northern Hemisphere is seen to be warme on the average than the Southern, except in high latitudes,[1] where the con verse is true, the land also being generally warmer than the sea in lov latitudes, but colder in higher latitudes. They also show that the distric of greatest heat, especially in summer, is the interior of continents, th deserts of Africa and Persia having a July temperature of 90°. The tem perature of the sandy *ground* in these parts is often above 160° F. Ther must, therefore, be some other causes modifying the effect of position a regards the equator. Among these are the prevailing winds, proximity t the sea, position of mountain chains, and the altitude of the land. W shall now discuss this last, leaving the others till we speak of Climate.

182. *Temperature depends on Height above the Sea-Level.*—Since th first effect of the sun's heat after it has warmed the surface of the earth to warm the parts of the atmosphere in contact with the surface, and sin this warmth is but slowly passed on through the higher layers, we find th the air near the surface is warmer than the air above. But there are oth reasons why the air is colder at a distance from the surface.

It is quite true that on high mountains the intensity of the *solar* radi tion is greater than in the valleys, and that therefore the traveller who there exposed to the direct rays of the sun may have his skin blistered b the great heat, though another in the shade may feel great cold. But th heat is not communicated to the air; for the air becomes rarer the highe we ascend, and also holds less moisture. Consequently it is but littl heated either by the luminous rays of the sun or by the rays radiated fro the rocks. There is thus no protective water-vapour in the atmospher to check the rapid radiation into space when the sun is not shining, an there is thus no store of heat retained in the soil as at low levels.

Another property of air also tends to diminish the temperature at grea heights. When a mass of air expands, heat is used up to perform thi work and the air becomes cooler. Warm winds, therefore, from a valley when forced up the sides of a mountain, expand in consequence of th diminished pressure at the greater height, *and in expansion become greatl cooled.* This diminution of temperature in ascending currents is greate with a dry wind than with a moist wind, as, in the latter case, while hea is lost through expansion, some is gained by the vapour that condense giving up its *latent heat,* so that this latent heat lessens the rate of cooling The diminution, too, is greater during the day than during the night greater in summer than in winter. In severe frosts, indeed, the tempera ture may rise with height, instead of falling, all the cold dense air remainin in the lowlands beneath. We thus see that the lower temperature of th air at greater heights is due to two chief causes, the diminishing thinnes and dryness of the protective coating of the atmosphere and the disappear ance of heat consequent on the expansion of the ascending air-currents.

[1] High latitudes are latitudes near the poles; and low latitudes, lati tudes near the equator.

This *vertical distribution of temperature*, as it is called, to distinguish it from the *horizontal distribution*, shown by the isothermal lines, which show the temperatures at the surface, may be reduced to a general rule. The rate of diminution may be taken on the average at a fall of 1° F. for every 300 feet of ascent.

183. **Land and Sea Breezes.**—*Winds* are movements of air in currents from one part of the atmosphere to another. They are caused by variations in the condition of the air in respect to heat and moisture, and, as these variations produce differences in atmospheric pressure, movements are set up, there being always an inflowing towards regions of low pressure. We shall here confine ourselves to the *local* movements called land and

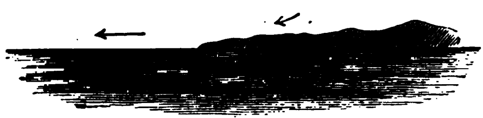


FIG. 159.—Land breeze by night.

sea breezes. These occur chiefly on the coasts of tropical countries, though they are also found during warm weather in our own islands, when not overpowered by a strong general wind. They are more frequent about islands and small peninsulas than in other situations. They blow alternately from the sea on to the adjacent land (sea breeze), and from off

FIG. 160.—Sea breeze by day.

the shore to the sea (land breeze). A little before noon the sea breeze begins in the offing and gradually extends to the coast, lessening and dying away towards the evening. A short period of calm follows, and then some time before midnight the land breeze comes from the shore and blows towards the sea until six or seven o'clock A.M. These winds are due to the different manner in which the sun's heat affects the land and water, and also to the different radiating power of the two

surfaces. The surface of the sea is not raised to so high a temperature during the day as the surface of the land, partly because the solar heat penetrates further into the water than into the land, but chiefly owing to the greater specific heat of water (see par. 74), in consequence of which it requires nearly five times as much heat to raise its temperature one degree as the rocks forming the land surface require.

On the other hand, the sea does not lose so much heat at night by radiation as the land does, and accordingly it preserves a comparatively equable temperature throughout the day. The temperature of the land surface thus undergoes far greater changes of temperature than the sea surface, and this is of course also true of the air lying above both. Calm prevails as long as the temperatures over land and sea are the same; but as the solar rays become hotter towards noon, the more strongly heated land communicates its heat to the overlying air, and this causes it to expand and become rarer. A diminution of pressure on the land surface is the result. In the *higher* air-regions above the land there is an overflow of the air *outwards* from the heated part towards the cooler air at some distance over the sea. Hence the pressure over the sea rises, and very soon afterwards an equalizing air-current arises in the *lower* parts of the atmosphere and flows *inwards* towards the heated land, and is therefore called a *sea breeze.* The strength of the sea breeze is not always the same. It increases until the difference of temperature between the land and sea is at its maximum, and then gradually diminishes until about equal temperatures are found.

As soon as the sun's rays cease the land cools down much more quickly than the sea, and hence the temperature of the air above the land falls. The air-masses over the land thus contract and the pressure increases. There is therefore *above* a current of air from the sea towards the land, which assists in increasing the pressure over the land and diminishes it over the sea. In accordance, then, with the general law that currents blow from regions of high pressure to those of lower pressure, an equalizing stream sets in from the land towards the sea and so develops a *land breeze.* The time during which a land

breeze blows is usually from an hour or two before midnight until six or eight o'clock in the morning.

Diurnal winds, similar to land and sea breezes, termed *mountain and valley winds*, prevail in some mountainous districts. The slopes of the mountain exposed to the sun's rays become more heated during the day than the land surface of the valley, and the air resting on the slope becoming hotter than that in the valley flows off above. A difference of pressure is thus set up, and a surface wind blows up the valley by day. At night the slope of the mountain quickly cools, and the air resting upon it becomes denser than that in the valley. A breeze from the mountain then passes down the valley in the night.

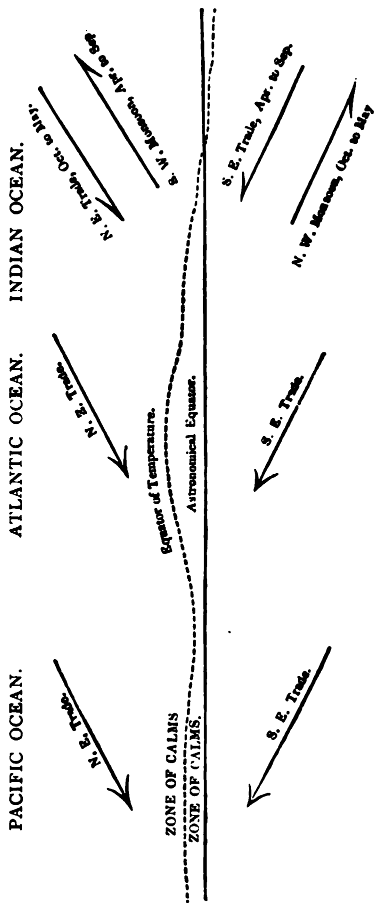


FIG. 161.—Diagram of winds within the tropics.

184. **Trade Winds, Monsoons, and Cyclones.**—Near the earth's equator, under the vertical rays of the sun, there is enormous evaporation and great heating of the surface with consequent heating of the air resting upon it. Hence arises an equatorial belt of low pressure (referred to in par. 174), for the hot moist air expands, and ascending flows off above towards the poles, thus reducing the atmospheric pressure near the equator.

This equatorial belt of low pressure, a few degrees in breadth, forms a *zone of calms*, with frequent heavy rains often accompanied by violent thunderstorms. This belt of calms (Doldrums) advances towards the north in summer, as the sun is then above the equator, and towards the south in winter, as the sun is then below the equator. In fact, it follows the *thermal equator*, as the line along which the greatest heat on the earth's surface at any season is called. The expanded and rising air of the calm belt leads to the steady inflow of surface winds

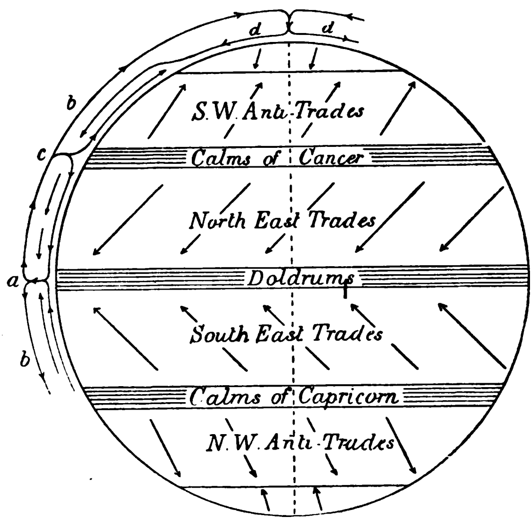


FIG. 162.—At *a* the heated air rises, to flow away towards the poles in the upper atmosphere; at *c* it descends, part returning to join the descending cooler air from the poles, and to help to form the north-east trades, and part passing onwards to form the south-west anti-trades.

from regions of greater pressure in higher latitudes towards the equator. If the earth were at rest, a north wind would prevail at the north side of the calm belt and a south wind on the south side of the calm belt. But the earth's rotation deflects these winds to the right in the northern hemisphere and to the left in the southern, their directions becoming more and more easterly as they approach the equator. These regular winds, *from the* north-east on the northern side of the equator, and

from the south-east on the southern side of the equator, constitute a regular system of currents known as the *trade winds.* Over the land the greater friction and the irregular distribution of temperature disturb their uniformity, and hence they are most marked in the open sea, where the surface temperature is more uniform.

The **trade winds,** then, are constant winds blowing in a regular trade or course over the oceans towards the equatorial region of low pressure, those in the northern hemisphere, starting about 30° N. lat. and being deflected towards the right by the earth's rotation, constituting the *north-east trades ;* and those in the southern hemisphere, starting about 30° S. lat. and being deflected towards the left, constituting the *south-east trades.* Both die out as they approach the belt of calms.

Beyond the borders of the trade winds in both hemispheres the prevailing winds are from the south-west or west, but these westerly winds are not so regular as the trade winds. These westerly winds arise in great part from the upper currents that flow from the equator, and descend to the surface about the thirtieth parallel of latitude, where they produce the *calms of Cancer* in the northern hemisphere, and the *calms of Capricorn* in the southern. Continuing northward or southward, and being deflected to the right or left according to the hemisphere (north or south) by the earth's rotation, they form the westerly winds or *anti-trades* of temperate latitudes (see Map. VIII.).

Monsoons are *periodic* winds that blow over the Indian Ocean and adjacent lands—a *north-east monsoon* during the winter months from October to March, and a *south-west monsoon* during the summer months from April to September. During the cooler half of the year, the north-east monsoon is, in fact, the regular trade wind of the northern hemisphere. The change to a south-west monsoon in summer is the result of the sun's heat upon the continent of Asia. In summer the heat upon the southern part of Asia is greater and the air less dense than that of the Indian Ocean, and consequently air passes from the region of higher pressure over the ocean to the region of lower in Asia, and, being deflected by the earth's rotation to the right, becomes the *south-west monsoon.* The

change of monsoons is usually accompanied by violent storms. It is this south-west wind laden with vapour that produces the great summer rainfall on the high range of mountains in the north of India (par. 218).

The variable winds of the north temperate zone either blow, as a rule, inwards towards a centre of low pressure, or outwards on all sides from a centre of high pressure. A wind-system in which the wind blows spirally around and in towards a centre of low pressure is called a **cyclone** (Gr. *kuklos*, a circle), as the isobars outside the centre have a more or less circular shape. A wind-system with light winds flowing outwards from a centre of high pressure is known as an **anti-cyclone.** "The direction in which winds blow spirally inwards in a cyclone is (in the northern hemisphere) opposite to that of the movements of the hands of a watch lying face upwards; in an anti-cyclone the opposite. The position of an anti-cyclone is usually pretty constant for days, or even weeks together, but that of a cyclone is constantly changing, as the centre of low pressure is always shifting, generally in a more or less easterly direction." Other revolving storms of wind and rain are known in different regions as *hurricanes*, *typhoons*, or *tornadoes*, as well as cyclones. (For a fuller account of winds, see "Advanced Physiography.")

CHAPTER XVI.

THE SEA.

185. THE entire surface of the globe is estimated at 197,000,000 of square miles, and of this a little more than one-quarter, 52,000,000, is occupied by land; and nearly three-fourths, 145,000,000, is covered by water. The land consists mainly of two great masses known as the Old World and the New World, and it is evident from looking at a terrestrial globe that the great mass of this land is situated in the Northern Hemisphere,

FIG. 163.—Western and eastern hemispheres.

there being about three times as much land to the north of the equator as there is to the south of it. Though the waters of the ocean surround the land on every side, yet they are broken up into certain areas by the arrangement of the land portions, and to these various parts we give particular names.

(1) The Atlantic Ocean, lying between the western shores of Europe and Africa and the east coast of America.

(2) The Pacific Ocean, lying between the west coast of America and the east coast of Asia.

(3) The Indian Ocean, lying between the south of Asia and the Antarctic circle.

(4) The Arctic Ocean, lying within the Arctic circle.

(5) The Antarctic Ocean, lying within the Antarctic circle.

We know that our earth is a globe or sphere in shape. If we imagine it cut into halves by a plane passing through the two poles and the middle of the Atlantic on one side, and through the Pacific Ocean on the other, we call that half which lies to the west of England the Western Hemisphere, and the half that lies mainly to the east of where we live the Eastern Hemisphere. These two hemispheres may be seen in any atlas.

But we may also suppose the globe to be divided into halves by a plane passing through the equator, and we should then get a Northern and Southern Hemisphere, a figure of which shows plainly the arrangement of land already referred to.

Again, the world may be supposed to be divided into halves by a plane perpendicular to a plane passing through the meridian of Greenwich, so that

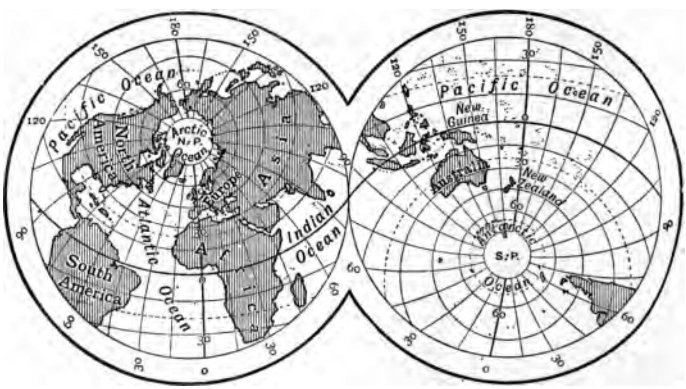


FIG. 164.—Land and water hemispheres.

London is the centre of one hemisphere, and a point (Antipodes Island) in the ocean near New Zealand the centre of the other hemisphere. This shows us what may be called the Land and Water Hemispheres, as the one is mainly made up of land and the other mainly of water.

186. **Composition of Sea-Water.**—The water of the ocean is not pure water, but contains dissolved in it various chemical substances known as salts. These salts amount in all to a little over $3\frac{1}{2}$ grains in 100 grains of water; or, in other words, $3\frac{1}{2}$ per cent. of sea-water by weight consists of dissolved salts: chloride of sodium or common salt is the chief, forming 2·7 of the whole $3\frac{1}{2}$ per cent. of saline ingredients.

Experiment 102.—Take two evaporating basins. Into one pour a certain volume (say 25 c.cms.) of water from the tap, and into the other an equal volume of sea-water. In both cases evaporate to dryness. Notice that there is hardly any residue from the fresh water, whilst the sea-water leaves a comparatively large amount of residue behind. This proves that sea-water contains dissolved in it a much larger amount of solid substance than fresh water.

Experiment 103.—Fill the flask used in Experiment 11 up to the mark with tap-water, and weigh. Note the weight. Empty it, and then fill up again to the mark with sea-water. Again weigh. Since the flask used both times is the same, the greater weight in the second case must be due to the fact that salt water is denser, or has a higher specific gravity than fresh water.

The following table exhibits the exact percentage composition of sea-water.

One hundred parts by weight of sea-water contain—

Water	96·470
Sodium chloride	2·700
Magnesium chloride	·360
Potassium chloride	·070
Magnesium sulphate	·230
Calcium sulphate	·140
Calcium carbonate	·003
Magnesium bromide	·002
Traces of iodides, silica, etc., estimated	·025
	100·000

Though the average proportion of salts is, as already stated, about three and a half parts in every hundred parts of water, yet there are slight variations.

In those seas which receive a large quantity of fresh water, and where there is little evaporation, as in the Baltic, the percentage of dissolved matter is lessened; while in such seas as the Mediterranean, where evaporation is greater than the supply, the percentage is increased. The highest percentage found in the *Challenger* expedition was 3·737 in water taken from the middle of the North Atlantic. The Red Sea, however, contains the saltest water, the percentage of dissolved matter being 4·3 This is owing to the great evaporation always going on, and because no fresh water is poured into it, the supply of water being kept up by a current through the Straits of Babelmandeb. The presence of these dissolved substances is evident to the taste, for sea-water is both salt and bitter. But the salts can be readily seen if a small portion of sea-water is evaporated. A number of crystals is then found in the basin, and on reference to the table of the composition of sea-water it will be seen that common salt (NaCl) forms by far the largest portion of these soluble materials. Each of the substances has its own crystalline form, but the cubical crystals of common salt are the most abundant. In the south of Europe and other warm districts sea-water is allowed to run into shallow beds, which are shut off from the sea. As the water evaporates, a crust of salt forms on the margin, which is afterwards taken out.

187. **How the Sea became Salt.**—It is probable that the waters of the sea have been salt from the time that the earth became cool enough to allow the vapours of the atmosphere to condense and collect in the hollows

of the surface. No doubt this original atmosphere had in it many saline vapours, and ever since this period the rivers and streams that flow from the land have carried in solution to the sea the various substances now found dissolved in it. As the water that evaporates from the sea is pure, the dissolved mineral matter being left behind, and as this water again falls on the land as rain, snow, etc., percolating through the rocks and dissolving such mineral matter as is soluble, it may be supposed that the saltness of the sea increases. There may be a very slight increase, but it must be remembered that there is a constant loss of this mineral matter in two ways. Some of it is carried back on to the surface of the land during storms and high winds, immense quantities of spray being often blown inland and carrying with it the dissolved salt. Another check to the increase of the saltness of the ocean is the requirements of the animals and vegetables that have their abode in it. The carbonate of lime ($CaCO_3$), and the calcium sulphate ($CaSO_4$), carried down in solution by rivers is the material out of which the hard parts of shell-fish, corals, foraminifera, etc., are built up. After their death these hard parts accumulate, and form the beds of limestone and chalk of which we have previously spoken. Silica (SiO_2), though existing in but minute quantity, 9 parts in 100,000 of water, is secreted by certain minute marine plants called *diatoms*, and minute animal forms called *Radiolaria*. It is probable that some of the silica is derived by these organisms from the fine clayey particles in suspension in sea-water. It may also be mentioned that sea-water contains a certain amount of gases in solution, chiefly air and carbonic acid. The oxygen of this air is required by the animals that live in the ocean, and is constantly being renewed in the wind-tossed waves.

188. **Density or Specific Gravity of Sea-Water.**—Compared with pure water, sea-water is found to be slightly heavier; its *mean* density being 1·0275, that of pure water being 1. The salter the water is, the greater its specific gravity. Fresh water, being specifically lighter, floats on the surface for a time, but gradually becomes mixed with the heavier water beneath. It is owing to this that after a heavy rain, or at some distance from the mouth of a large river, fresh water may often be taken from the surface. As water is nearly incompressible, the density at various depths shows but very slight increase, though the pressure increases enormously. At a depth of 1000 fathoms there is a pressure of about one ton to the square inch. Since the density depends chiefly on the amount of salts in solution, it is found that the specific gravity of the open ocean is greatest where the saltness is greatest. This occurs where there is great evaporation, and where we have winds constantly blowing over the surface, viz. in the trade-wind regions of the North and South Atlantic. As a rule the density diminishes from the surface to about 1000 fathoms, and then increases again to the bottom. Near the coast where rivers enter the sea, and towards the poles where much rain falls, and ice and snow are continually melting, the specific gravity diminishes.

189. **Sea-level.**—The level of the sea at any place is constantly varying on account of waves and tides, but the level surface half-way between mean high and mean low water is termed the *mean sea-level* at that place. Heights above sea-level on the ordnance survey map of Great Britain are heights above "mean sea-level" at Liverpool. Owing to currents,

prevailing winds, etc., this mean sea-level at Liverpool is not the mean sea-level at other places on our coasts. But in other parts of the world there are greater disturbing causes. The gravitative attraction of large mountain masses raises the mean level of the sea surface in their neighbourhood, so that it has been estimated that at the mouth of the Indus, where the attraction of the Himalayas is effective, the mean sea-level is 300 feet further from the centre of the earth than on the coast of Ceylon. It thus appears that there is no one definite mean sea-level, and comparisons of heights of distant places above sea-level are somewhat uncertain.

190. **Instruments of Research.** *Depths of the Sea.*—Within the last few years much information has been gathered regarding the depth, temperature, and living forms of the ocean. The English, American, Norwegian, and other Governments have sent out expeditions to explore the deep seas. The most important of these was the *Challenger* expedition. The *Challenger* was an English screw corvette which steamed away from Sheerness on December 7, 1872, and for three years and a half investigated the waters of the globe. During the first two years of the cruise Sir George Nares was in command of the ship, and he was succeeded at the end of that time by Captain Frank Thomson. During the whole time the scientific work was under the direction of Sir Wyville Thomson, assisted by Mr. John Murray and other men of science. We will now give a brief account of the methods followed on board such an exploring ship.

The depth of the ocean is found by the method of sounding. The ordinary method of sounding is to let down a weight with a line attached. This answers well enough in shallow water, but fails at great depths, because when the weight strikes the bottom cannot be learnt, as the line still continues to run out. After many experiments it was found that if a very heavy weight were attached, the sudden change in the rate indicated when the bottom was reached. But such a heavy weight could not be drawn up again, and Lieutenant Brooke contrived a simple means by which the weight or sinker should be detached on striking the bottom. This method has been still further improved upon, and the mode of sounding adopted by the *Challenger* was as follows.

A block and pulley with "accumulators" is fastened at the end of the ship's fore yard. These "accumulators" are bands of indiarubber attached between two discs of wood for the purpose of breaking the strain on the

sounding line. At the bottom of the accumulators another block is hooked with the sounding line rove through. To the end of the sounding line is attached the sounding rod or tube. The sounding line is marked at every 25 fathoms,[1] and lengths of 3000 fathoms are kept on each reel. The sounding rod consists of a long cylinder of brass tubing about 2 inches in diameter, and fitted with a pair of butterfly valves at the lower end, opening inwards. The water that enters the lower end of the tube, while it is sinking, passes out through holes in the upper part. Round this tube sinkers of iron, each 56 lbs. in weight, are attached, 1 cwt. being usually allowed for each thousand fathoms. These sinkers are so fastened to the tube about 18 inches from its lower end that they are detached on reaching the bottom, and left there. Owing to the enormous pressure at great depths, it would be impossible to draw them up. It is known when they have reached the bottom and fallen off by the sudden change in the rate at which the line has been running out. On striking the bottom the sounding tube is forced into the mud, and the valve prevents the materials thus obtained from falling out. In this way not only is the depth at a particular place obtained, but specimens of the ocean floor are brought up. In Globigerina ooze the tube sinks 8 or 9 inches, and in clay about 2 feet.

FIG. 165.—The Hydra sounding rod.

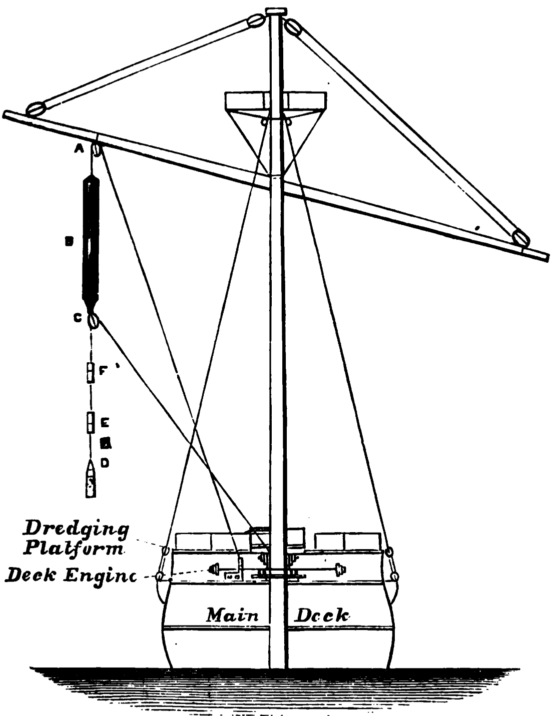
FIG. 166.—Baillie's sounding rod.

Figs. 165 and 166 give a view of two of the sounding rods used during the voyage of the *Challenger*, with four weights or sinkers in position round the tube. These sinkers are cylindrical pieces of iron with a hole through the centre, through which the sounding tubes pass. They rest on an iron disc or washer, which is held in position by a wire fastened to an arrangement at the upper end of the rod, so that on reaching the bottom the wire is set free, and the sinkers slide off.

But there are also other instruments attached to the sounding line when it is sent down. These are a specially constructed and protected self-registering thermometer to measure the temperature, a pressure gauge to register the pressure of the superincumbent column of water, and a water-bottle to bring up a specimen of water from the depth reached. The thermometer used in deep-sea sounding has to be specially constructed to resist the enormous pressure to which it is subjected. Hence the bulb which contains the mercury, or other fluid by whose expansion and contraction the temperature is measured, is enclosed in a strong glass case, so that its indications are not affected by the external pressure. Thermometers are sent down to different depths,

[1] 1 fathom = 6 feet; and 880 fathoms, or 1760 yards, or 5280 feet = 1 mile.

ıe temperature ascertained both at the surface and at various The water-bottle is really a metal cylinder having a stopcock ı end connected by a rod, and so constructed that the water reely through it while descending, but when an upward movement the rod shuts the stopcocks and encloses a specimen of the water. ıving the ship the sounding line with the instruments attached e represented by the diagram (Fig. 167), though it should be that, through fear of damage from the motion of the ship, the



7.—Diagram to illustrate method of sounding on board H.M.S. *Challenger*. ɔlock secured to fore yard; B, accumulators; C, block through which sounding passes; F, pressure gauge and thermometer. E, water-bottle; D, sounding and sinkers.

ng rods and sinkers were lowered into the water before the water- and other instruments were attached. At first the line is let out , but on reaching about 400 fathoms it is allowed to run out freely, .p being kept over the place where the sinkers entered the water. .terval of time between the marking of every 100 fathoms is noted. intervals gradually increase, owing to the sinkers being retarded in escent by the friction of the increasing amount of line passing through

the water. But the intervals are sufficiently regular to show that any sudden lengthening of the time indicates that the bottom has been reached. The bottom having been reached, the line is carefully drawn up by means of a donkey engine. When the thermometer, water-bottle, and sounding tube have reached the surface they are taken on board and detached from

FIG. 168.—Sea-bed around Britain. The darkest shading indicates land above 600 feet high; the next shading shows the present outline of the land; the lightest shading indicates the sea floor at depths of 100 fathoms and less, and shows what would become land were the bed elevated this height.

the line. The temperature indicated by the thermometer is read off and entered into a book; the water and the contents of the sounding tube are carefully preserved for examination.

For measurements where there was no reason to expect a depth of over

MAP VI.—Atlantic Ocean, showing depths.

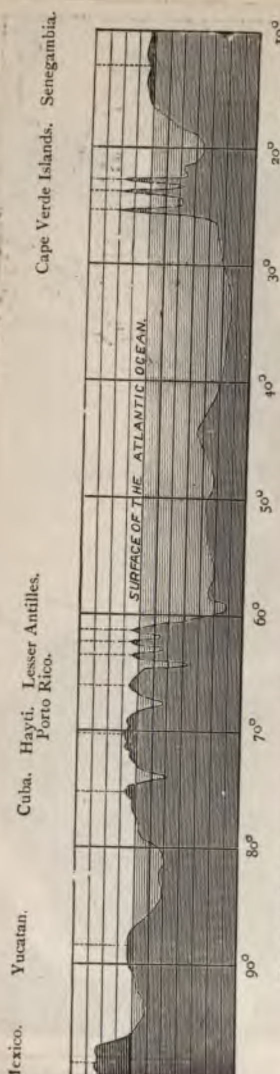


FIG. 169.—Section across the Atlantic Ocean between Senegambia and the table-land of Mexico, 7000 feet high. The greatest depth shown is about 17,000 feet.

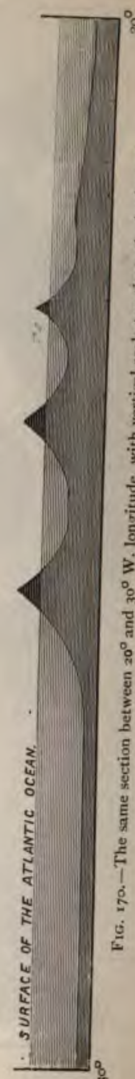


FIG. 170.—The same section between 20° and 30° W. longitude, with vertical scale ten times the horizontal.

1000 fathoms the ships used an ordinary deep-sea lead, fitted at its base so that an iron cylinder with a butterfly valve can be screwed on. The whole can be drawn up from such a depth.

Dredging.—Besides the sounding apparatus, a dredge or trawl is also used to obtain specimens of the creatures living at various depths, or on the ocean's floor. During the latter part of the *Challenger's* voyage a trawl of the ordinary shape was generally used. It consisted of a V-shaped net, one side of which was fastened by straps to a stout beam of oak, while the other side of the net hung loose.

191. **Depth and Form of the Ocean Floor.**—As a rule the sea is shallowest near the land, though in a few cases there is a sudden descent to a great depth at a very short distance from the coast. Lowlands have usually shallow seas near the coast, and highlands deep water. Thus the seas around the British Islands are all comparatively shallow. The greatest depth in the German Ocean is about 100 fathoms, and in some parts, as the Dogger Bank off the northern coast of England, there are very shallow sand-banks; in the Irish Sea the depth is 40 fathoms, and at Dover Straits the depth is less than 30 fathoms. For about 100 miles, too, off the west coast of Ireland and Scotland the sea is comparatively shallow, and the slope of the Atlantic but gentle. The British Islands are thus situated on a submerged plateau, and in all probability once formed part of the European continent, separated only from Norway by a gulf where the water is now 300 fathoms deep. In a similar way New Guinea is proved to have once been joined to Australia. From the plateau on which the British Islands are situated there is a rather rapid descent into deep water to a depth of about 12,000 feet. This stretches as a deep valley for hundreds of miles to the west, and ranges north and south almost parallel with the face of the Old World. A similar wide and deep valley is found to run parallel to the American coast, while between these two deep marine valleys rises a ridge which runs down the centre of the Atlantic. The upper surface of this central ridge is only about 10,000 feet below the surface, but the two great ocean valleys on each side of the ridge attain a depth of 18,000 feet. The accompanying Map III., p. 229, from Dr. Haughton's "Lectures on Physical Geography," shows the form of the bottom of the Atlantic Ocean. The unshaded portions are less than one geographical mile in depth—under 6000 feet. The shaded portions are more than one mile and less than two miles in depth, between 6000 and 12,000 feet. The black portions are more than 12,000 feet in depth. This map shows—

"(*a*) How closely the contour lines of 6000 feet and 12,000 feet cling to the coasts of Africa and South America.

"(*b*) The remarkable central ridge ('Dolphin,' 'Connecting,' and 'Challenger') that divides the Atlantic into deep canals, keeping near Africa and South America respectively.

"(*c*) The islands of St. Helena, Trinidad, and Fernando de Noronha (especially the latter), rising abruptly from the deepest parts of the sea bottom."

Another mode of illustrating the depth of the ocean is to show a section between two coasts. Fig. 169 is such a section between the coast of Africa and the coast of Central America. From this section we see that the West Indian islands shut off the deep waters of the Atlantic from the shallower basins of the Mexican Gulf and Caribbean Sea. But it must be borne in mind that in such a section the vertical scale is a great many times more than the horizontal scale. To guard against the false impression that may


THE WORLD
Showing
DEPTHS
Reference
Under one mile
One mile to three
Over three miles
Over five miles
ARCTIC OCEAN
ANTARCTIC OCEAN
NORTH AMERICA
SOUTH AMERICA
GREENLAND
EUROPE
ASIA
AFRICA
AUSTRALIA
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
Arctic Circle
Antarctic Circle
Tropic of Cancer
Tropic of Capricorn
Gulf of Mexico
Caribbean Sea
Gulf of Guinea
Black Sea
North Sea
Arabian Sea
Bay of Bengal
Sea of Okhotsk

arise if this is not remembered, a small portion of this section which includes the Cape Verde Islands is repeated (Fig. 170), though even here the vertical is ten times the horizontal.

On reference to the general map of ocean depths, which is shaded for depths different from those taken as the basis of shading in the Atlantic Ocean map, it will be seen that each of the deep valleys of the Atlantic contains still deeper abysses. One of these lies to the north-east of the West Indies; and here, at a distance of about 100 miles north of the island of St. Thomas, the *Challenger* obtained a sounding of nearly 4½ miles. Since then H.M.S. *Penguin* has obtained soundings of over 5000 fathoms in the Aldrich Deep of the South Pacific, south of the Friendly Isles.

The average depth of the Pacific Ocean has been estimated at between 15,000 and 18,000 feet, which is slightly greater than that of the Atlantic. The deeper portions may be learnt on reference to the map. The western portion of the North Pacific in particular shows some very deep depressions. To the east of Japan lies a long deep trough which in one part has furnished the sounding of nearly 5½ miles. This abyss is often called the Tuscarora Deep. South of the Ladrone Islands, in the Caroline Archipelago, there is also a deep abyss where the *Challenger* obtained a sounding of nearly 27,000 feet. In the South Pacific, south of the Friendly Isles, one sounding of over 5155 fathoms has been obtained. A submarine ridge connects the Friendly Islands, the Fiji Islands, and the New Hebrides.

In each ocean the greatest depths are in the Northern Hemisphere and towards the western border. Towards the north in the Northern Hemisphere the ocean rapidly becomes shallow. Between Great Britain and Iceland the depth is mostly under 6000 feet, and in Behring's Straits the depth is only about 150 feet. The southern portions, however, of the great oceans are mostly of average depth. (See coloured map.)

The Indian Ocean has an average depth of about 12,000 feet, and the deepest soundings have been taken on the eastern side. The bed of the ocean has none of the steep ridges and jagged outlines of mountain scenery. There are great ocean plains where the ground is level; there are submarine peaks having steep descents; there are submarine plateaux often connecting together continents and islands; there are enormous valleys, and there are deep abysses reaching to five miles, and perhaps beyond. But in all cases the smoothing and rounding influence of the water has worn away the sharp edges so often seen on land, and has given to the steepest descents a roundness of curve and outline. It is interesting to observe that the deepest sounding, about 5⅘ miles, in the South Pacific, somewhat exceeds the height of the highest mountain. Mount Everest has a height of 29,000 feet above the sea level. And it must also be noted that the mean height of the land, 1000 feet, is only about one-twelfth the mean depth of the whole ocean, 12,000 feet. If as much land were carried into the ocean as would reduce the two to a common level, the ocean would still have a depth of about 10,000 feet. The average height of Europe, Asia, Africa, and South America is reckoned to be about 1130 feet; of North America, 750 feet; and of Australia, 500 feet.

192. Temperature of the Ocean.—As already remarked, much information has lately been gathered respecting the temperature[1] of the sea at various depths by the researches made during the voyage of the *Challenger* and other vessels sent out for scientific exploration. Thermometers

[1] Temperatures are expressed in degrees Fahrenheit when not otherwise indicated.

protected from the outward pressure of the water are let down during the process of sounding to various depths, or several thermometers are fastened at intervals along the rope, and what are called serial temperatures are thus obtained. It must be remembered that the freezing-point of sea water is nearly five degrees below the freezing-point of pure water, and that, unlike fresh water, it contracts down to its freezing-point, thus becoming heavier the colder it gets. It should also be noted that land is more readily heated by the sun's rays than the waters of the sea, but it does not retain its heat so long. The water has a greater specific capacity for heat than the rocks forming the land; that is, it requires four times as much more heat to raise its temperature one degree than does the land. This greater amount of heat is given off as the temperature is lowered, so that warm currents of water may thus give up a considerable quantity of heat to overlying colder air. On the other hand, cold currents of water from polar regions may reduce the temperature of the overlying air. These currents, of which we have just spoken, will be treated of more fully in an Advanced Course. We must, however, point out that the great solar heat in the equatorial regions not only warms the waters in that part, causing them to become specifically lighter, but turns an enormous quantity into vapour. These causes produce a flow of the heavier colder water from the poles to the equator, and a contrary flow of the surface of the lighter and warmer water from the equator to the poles. The direction of these currents is greatly modified by the configuration of the coast, and the ridges in the bed of the sea. We shall afterwards prove the earth is a globe rotating on its axis from west to east, and carrying with it the waters of the ocean and the gases of the atmosphere. When, therefore, either water or air is transferred from one part of the globe to another, where the rate of motion is different, the direction of the water or air-current becomes modified. In passing from the polar to the equatorial regions, where the rotatory speed is greater, such a current is drawn towards the west. A constant current flows from the cold Antarctic regions towards each of the great oceans. This forms in the South Atlantic what is called the equatorial current. On reaching the coast of Brazil the equatorial current divides into two branches, the northernmost of which passes through the Caribbean Sea into the Gulf of Mexico. Here, under the powerful rays of the tropical sun, its waters become heated, and it issues from the Straits of Florida as a mighty river, with a temperature more than 20° F. higher than the surrounding water of the North Atlantic. Assisted by the prevalent south-west winds, the surface drift of warm water from this stream is carried to the shores of Britain, and even of Spitzbergen. The cold current in the northern part of the Atlantic comes through Davis Strait along the coasts of Labrador and Newfoundland.

193. **Surface Temperature of the Sea.**—The temperature of the *surface* of the sea varies according to the latitude or distance from the equator, and also according to the seasons of the year, except in the equatorial regions, which are affected but little by change of season. Generally speaking, the surface of the ocean near the equator has an average temperature of about 80°, and this diminishes as we pass towards the regions of perpetual ice round the poles. The highest temperature is found about 6° N.,

and there the sea is usually warmer than the air. In the Northern Hemisphere there is a rise in the surface temperature of the sea in summer and a fall in winter, the epoch of highest surface temperature being in August, and that of lowest temperature in February—a month later than the corresponding turning-points in the temperature of the air. The same is true of the waters of the Southern Hemisphere—a rise in the *southern* summer and a fall in winter. The highest mean surface temperature is that of the southern part of the Red Sea, which is 90°.

Areas of high temperature from 84° to 85° are the China Sea, the Bay of Bengal, a district south of Sumatra, a portion of the Central Pacific, and the sea in the Gulf of Mexico to the Bahama Islands. Around Britain the temperature of the sea varies from about 49° in February to 60° in August. Owing to the existence of currents and other causes the lines of equal temperature in the temperate regions do not follow the parallels of latitude, though they correspond more closely in the case of the Pacific Ocean than in the case of the Atlantic. There is, however, never the same striking variation in the temperature of water at any place that there is in the case of air. Between the hottest and coldest part of the day there is seldom a difference exceeding one degree in the case of the sea. The daily change in the temperature of the air over the sea is nearly four times greater than that of the water on which it rests.

194. **Deep-sea Temperatures.**—We may summarize the chief facts now known regarding the temperature of the deeper parts of the sea as follows :—

(*a*) In the open sea, far from coasts and barriers, a continual decrease of temperature from the surface takes place as the depth increases, quickly at first, and then more slowly, until at depths of 3000 fathoms a temperature of about 35° F. is reached, and in still deeper areas a temperature as low as the freezing-point of fresh water, 32° F.

(*b*) The above is only true of the open sea, because where a submarine ridge exists, it retards the movements of the lower and colder waters, while the higher water passes over the ridge and fills up the area. Thus in the Sulu Sea the temperature falls rapidly from 80° at the surface to 50·5° at 400 fathoms, and this continues up to a depth of 2500 fathoms. Hence this sea is apparently surrounded by a ridge separating it from the ocean depth. In the same way the shallow Strait of Gibraltar (200 fathoms) cuts the Mediterranean off from the general movements of the waters in the Atlantic, thus preventing the entrance of any cold polar water ; and hence we find *in this sea a constant* temperature of about 54° at a depth beyond

100 fathoms. A similar explanation probably accounts for the finding of two such different temperatures as 29° and 43° at nearly the same depth between Scotland and the Faroe Islands.

(*c*) The layer of water at the bottom of which a temperature of 40° is found varies from 300 to 1000 fathoms in thickness, but the great mass of ocean water lies below this layer (see Fig. 171). This upper and comparatively thin layer of warm water is usually much thicker in the North Atlantic than in the South Atlantic, a fact probably due to the large influx of heated water brought by the Gulf Stream.

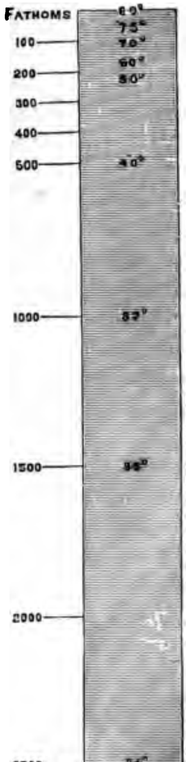


FIG. 171.—Diagram of a column of sea-water near the equator, showing the temperature at various depths. (A fathom equals 6 feet.)

(*d*) The bottom temperature of the Pacific is on an average one degree lower than that of the Atlantic. In the North Pacific it was often below 35°, while in the South Pacific a temperature of 32·5° was found, and still further south (53° 55′ S. lat.) the thermometer registered 31° at a depth of 1950 fathoms. In the Arctic Seas the water has been observed warmer beneath than at the surface, though at the bottom and at the surface it may be below the freezing-point of fresh water.

(*e*) The temperature of the sea sinks more rapidly over shoals and shallows than in the open sea. The presence of cooler waters in these positions is probably caused by the colder deep layers being deflected upwards.

(*f*) "All *inland* seas, at great depth, represent the mean temperature of the earth in the latitude where they are situated; whilst in the *ocean* the low temperature of the bottom in every latitude is produced by the cold currents setting in eternally from the polar regions." These cold polar waters, having a higher specific gravity than the warmer surface waters, flow along the ocean floor towards the equator, the warmer and relatively lighter waters from the tropical regions flowing in the opposite direction. As the Arctic Sea is much less open to the Pacific and Atlantic (Behring's Strait is only 60 miles wide), it is thought that the greater part of the cold and dense water near the ocean floor is an indraught from the unconfined Antarctic seas.

195. **Colour of the Ocean.**—Sailors sing of the "deep blue sea," and it is quite true that far from land and in considerable depths the sea possesses a pure bluish tint. Nearer the shore, however, the shallow water has a pale green tint, owing to the amount of suspended matter, the reflection from the sandy bottom mixing with the blue of the water. In some parts the varying colour is due to the numerous small seaweeds floating in it, or to the countless

microscopic animals present. The vast quantity of yellowish muddy sediment brought down by the great Chinese rivers accounts for the name given to the Yellow Sea.

196. **Action of Sea on Earth's Crust.**—Wherever the sea-coast is fringed by hills, these are eaten into and gradually worn back by the action of the sea. The incessant action of the waves breaking against the shores, especially during storms, tears away and wears down the rocks, which often fall from the cliffs in immense masses.

This destruction goes on faster with the same kind of rock when the cliffs present a vertical face to the waves. Where the rocks dip seaward the action of the breakers falling on them is greatly diminished, as they roll up the slope with little opposition, and without doing much damage. In the end, however, with the aid of atmospheric agencies their disintegration is at last effected. Portions become detached, and roll down the rocky declivity into the seething water below.

This erosion of the coast is greatly assisted by the action of the rain and frost. The water getting between the fissures becomes frozen in the winter months, and the expansive force exerted during freezing widens the fissures and loosens the particles. The huge fragments thus broken off are caught up and hurled about by the waves. They are then broken up into smaller pieces, and the ceaseless roll of the waves wears off their sharp angles, and reduces them to the smooth rounded pebbles which form the gravel and shingle of many parts of the seashore. These undergo still further destruction, for in time the shingle is ground into sand, and the sand into mud. The finer this rock *débris* becomes, the further is it carried out to the sea by the action of the tides and currents.

In the annexed diagram we have the section of a cliff, the upper part of which is composed of a hard rock, such as sandstone, *a*, resting upon a softer rock, such as marl or clay, *b*. The action of the sea on the cliff would wear away the soft rock quickly, and so undermine the cliff as in time to cause masses of the hard rock to fall in a heap at the base, *c*. These for a time would protect the lower part from further destruction. But the action of the waves would eventually break

them up and round them into *shingle*, *d*, and at last grind these into *sand*, carried further out at *e*. The finest particles of all, especially those derived from the softer rocks, would be carried out as *mud* to a still greater distance.

Those who have merely listened to the rolling pebbles on a sloping beach, watching the incoming wave hurl them up the slope and the retreating wave carry them rattling down again, can have no idea of the immense force exerted by the huge breakers striking an exposed ocean coast during a heavy gale of wind. On the west coast of Ireland, at Land's End in Cornwall, and among the Western Islands of Scotland, it is sometimes equal to about three tons on a square foot. Thus a surface of only two square yards might sustain a blow from a

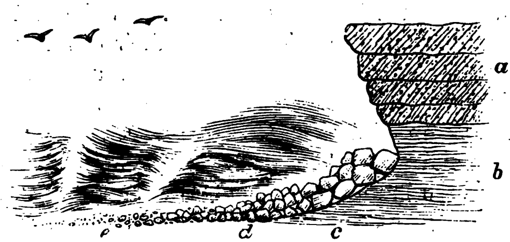


FIG. 172.—Action of the sea on the rocks of the coast.

heavy Atlantic breaker equal to about fifty-four tons. In such situations the rocks are often scooped and hollowed out into the most fantastic forms. Portions somewhat harder, or more favourably situated, have better resisted the action of the waves, and these stand out as headlands, or detached portions, as "needles" or "stacks." This unequal action on the harder and softer substance also gives rise to channels, creeks, and coves of every variety of form.

The destructive effect of the water of the sea is greatly aided by the boulders, pebbles, and sand which the waves toss about: just as the sediment carried in the waters of a running stream assists in grinding away the banks, so the sea uses the masses and shingle of the beach as instruments to pound and batter the cliffs of the shore.

We have thus seen how the sea is continually wearing away the land, and how rapid this destruction may be when the materials of the cliffs are but

soft. The comparatively soft strata of chalk that form the sea cliffs of Kent and Sussex are worn away (when not protected) at an average of from one to two feet a year. The Isle of Sheppey has lost fifty acres of land in the space of about twenty years. On some of the eastern parts of the shores of England the crumbling clay that forms the sea cliffs suffers a loss of from one to three yards a year. Tynemouth Castle now stands at the edge of the sea, though a strip of land formerly intervened. The ancient sites of some former towns and villages, such as Auburn, Ravenspur, and Hyde on the Yorkshire coast, now lie buried beneath the sea. "During the most violent gales the bottom of the sea is said by different authors to be disturbed to a depth of 300, 350, or even 500 feet, and Sir Henry de la Bêche remarks, that when the depth is fifteen fathoms the water is very evidently discoloured by the action of the waves on the mud and sand of the bottom. But in the deep caves of ocean all is tranquil, all is still, and the most dreadful hurricanes that rage over the surface leave those mysterious recesses undisturbed."

It must be noted that the sea is not eating away the land on every shore. In some parts are places sheltered from the action of the waves, and some shores have for a long distance seaward a level sandy beach, on which the waves spend their force without injuring the shore. In other places the sea, assisted by currents and winds, piles up ridges and hills of sand on the shore. Sea-shore sand consists of the water-worn particles of previously existing rocks reduced to small grains. It is partly brought down by rivers where it was held in mechanical suspension, and partly derived from cliffs on the sea-shore. The masses broken off the cliffs are first reduced to pebbles or shingle, and then, by the continual attrition of these produced by the rolling of the waves, they are reduced to small rounded grains. The most abundant material composing sand is quartz grains, but mixed with these there is often a quantity of calcareous material formed by the trituration of shells. Coral sand is derived mainly from the breaking up of coral rocks.

197. **Deposits on the Sea Floor.**—Messrs. Murray and Renard divide the deposits on the sea floor into (1) *terrigenous deposits*, or deposits derived from the wasting of the land, and carried down as sediment by the action of rivers, waves, and other movements of the water; and (2) *pelagic deposits*, or deposits found only in the deeper regions of the ocean basin.

The *terrigenous deposits* consist of (*a*) shore formations, blue mud, green mud and sand, red mud—found in inland seas and along the shores

of continents; (*b*) volcanic mud and sand, coral mud and sand—found around oceanic islands and along the shores of some continents. The *pelagic deposits* include pteropod ooze, Globigerina ooze, diatom ooze, Radiolaria ooze, and red clay.

As already remarked, the detritus or waste material produced by the action of the waves is deposited at no great distance from the shore, and shingle beds are not often met with at a distance of a mile from the coast. The finest particles of all are not carried further than 200 miles from the shore. These fine particles give rise to the *greenish* or *blue muds* so often found at depths of from 100 to 700 fathoms. This blue mud is the most extensive deposit now forming near the great continents and in large inland seas. Where large rivers enter the sea-portions of the finest material may be carried to still greater distances. These deposits, now forming near the shores of continents and large islands within 200 miles of the shore, resemble in all respects the sedimentary rocks of which we have spoken, and may at some distant period form the chalks, sandstones, shales, and conglomerates of future land. In the deeper parts of the ocean very

FIG. 173.—Section of Gravesend chalk, showing shells of foraminifera (highly magnified).

FIG. 174.—Organisms in Atlantic ooze, chiefly foraminifera, with a few radiolaria and sponge spicules (highly magnified).

different deposits are found. North of lat. 50° S., at depths varying from 250 to 2900 fathoms, a fine, light-coloured ooze or silt called *Globigerina ooze* is found. It consists chiefly of the minute calcareous shells of Globigerinæ and other Foraminifera mixed with same silicious shells of Radiolaria. At greater depths this "modern chalk of the Atlantic" passes into red clay. In some places the calcareous ooze consists of the thin transparent shells of another class of animals (molluscs), called *Pteropods*. *Radiolarian ooze* is a deposit met with in the Western and Middle Pacific. It consists of minute perforated silicious shells, formed by tiny creatures called Radiolaria, that live in all zones, and secrete silica for their skeletons. *Diatom ooze* consists of the flinty frustules or cells of diatoms, tiny *plants* that live on the surface, and after death sink to the bottom. These microscopic cells or valves are found in areas of great depth far from land. *Red* and *chocolate clays* form the chief deposit at the greatest depths. These are mostly of volcanic origin, and are probably produced by the volcanic dust carried by the winds, or from the decomposition of the pumice-stone borne

ıves. The colour is mainly due to the presence of iron and man- ıides. Mixed with these clays, especially in the South Pacific, ıbers of sharks' teeth and the hard compact ear-bones of whales ıght up by the dredge.

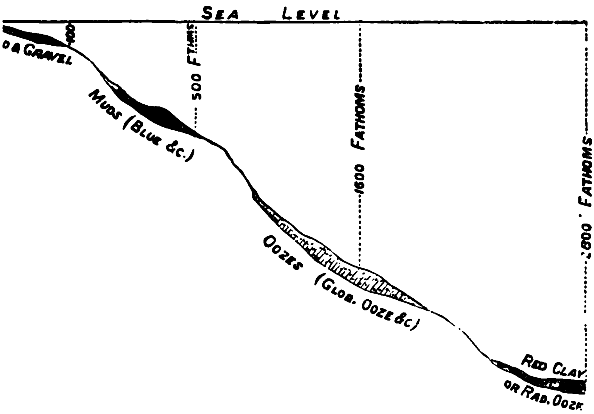


FIG. 175.—Diagram showing oceanic deposits at various depths.

ollowing table is derived from the *Challenger* Report on Deep- ıits :—

e deposits are classified as follows :—

deposits be- ɔo fathoms.	Red clay. Radiolarian ooze. Diatom ooze. Globigerina ooze. Pteropod ooze.	**Pelagic deposits** formed in deep waters far away from land.
	Blue mud. Red mud. Green mud. Volcanic mud. Coral mud.	**Terrigenous deposits** formed in deep and shallow water close to land masses.
vater deposits ı low - water ıd 100 fathoms.	Sands, gravels, muds, etc.	
deposits be- high and low ıarks.	Sands, gravels, muds, etc.	

CHAPTER XVII.

OCEAN CURRENTS.

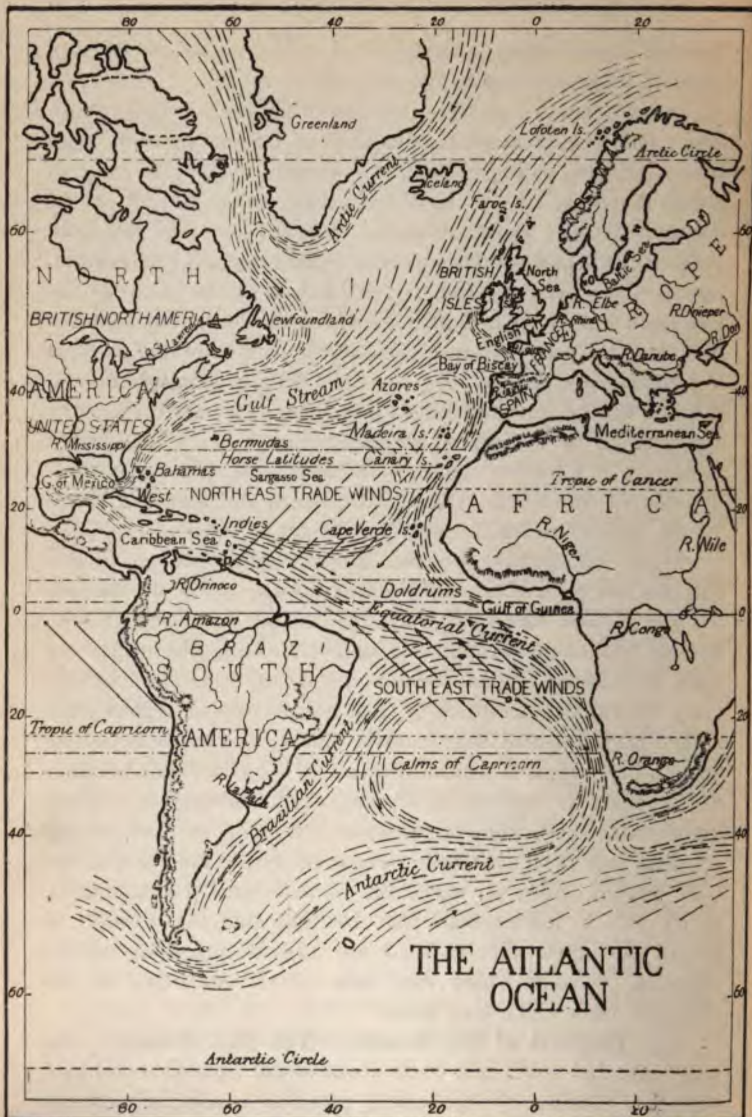
198. **Causes of Currents.**—Great stream-like masses of water called *currents* are found passing along the surface of each great ocean from one part to another, the general effect being to transfer warm water from equatorial regions towards polar regions, and to cause an underflow of cold water from polar regions towards the equator. It is important to seek the cause of these ocean currents and what determines their direction. One cause, no doubt, is the difference of temperature between equatorial and polar regions, for water is expanded and made specifically lighter by heat, so that the warm surface-water of the tropics will tend to flow away towards the poles. This, however, is not the main cause of oceanic circulation, for it is not sufficiently great to account for the large currents observed, and another important agent plainly acts. The chief cause is the direct frictional action of the constant winds on the surface of the water, since in each ocean the currents move in the same general direction as the winds. A wind sets the surface water in motion, and as the wind continues in the same direction, the motion is transferred by friction to lower and lower layers down to a depth of 400 or 500 fathoms. In the Indian Ocean the direction of the currents changes with the direction of the monsoons. Actual experiments also show wind to be an effective cause of currents. By the aid of a pair of bellows, and a vessel of water with sawdust floating on the surface, the production of surface currents can be easily shown. A model of the Atlantic Ocean has been constructed, and on imitating the action of the prevalent winds by air

currents blown from a number of tubes, a system of tiny currents corresponding to the real ones is set up.

In consequence of the operation of the trade-winds, therefore, there is a great westerly equatorial current in each great ocean. Owing to the obstacles presented by the east coast of South America, by the East Indian Archipelago, and by the coast of Africa, these equatorial currents are deflected both towards north and south temperate regions (see maps). Further, just as winds are deflected by the rotation of the earth on its axis from west to east, so also are currents; so that, in whatever direction the water or air moves on the surface of the earth, it is deflected towards the *right* in the northern hemisphere and towards the *left* in the southern hemisphere, the observer being supposed to be looking in the same direction as the current is flowing. All these causes combined lead to a huge whirl or eddy in the North Atlantic, the South Atlantic, the North Pacific, the South Pacific, and the Indian Oceans.

Much information on the *direction* and *speed* of ocean currents has been obtained by observations on the movements of wrecks and driftwood, and by actual experiments with floating bottles thrown out in certain positions, and picked up again by passing vessels or when cast ashore. Ocean currents carry enormous quantities of heat from tropical regions into higher latitudes, and thus modify climate. The immense influence of currents is well illustrated by the fact that Labrador, whose coast is washed by a cold Arctic current, is a bleak inhospitable land, while countries in the same latitude, on the opposite side of the Atlantic, tempered by the influence of the Gulf stream, enjoy an agreeable climate with a temperature nearly 20° F. higher than that naturally due to latitude. It should be noted that *currents* are named according to the direction *towards* which they flow—*winds* according to the direction *from* which they blow.

199. **Currents of the Atlantic—The Gulf Stream.**—The north-east and south-east trade winds of the Atlantic, combined with the rotation of the earth, produce equatorial currents that pass from the African to the South American coast. Near Cape St. Roque, in Brazil, the westerly equatorial current is



THE ATLANTIC OCEAN
Greenland
Arctic Current
Iceland
Lofoten Is.
Arctic Circle
Faroe Is.
NORTH
BRITISH NORTH AMERICA
BRITISH ISLES
North Sea
Baltic Sea
R. Elbe
R. Dnieper
R. Don
R. Danube
Newfoundland
English Ch.
FRANCE
Bay of Biscay
SPAIN
AMERICA
UNITED STATES
R. Mississippi
Gulf Stream
Azores
Madeira Is.
Mediterranean Sea
Bermudas
Horse Latitudes
Canary Is.
Bahamas
G. of Mexico
Sargasso Sea
Tropic of Cancer
West Indies
NORTH EAST TRADE WINDS
AFRICA
Caribbean Sea
Cape Verde Is.
R. Niger
R. Nile
R. Orinoco
Doldrums
Gulf of Guinea
R. Amazon
Equatorial Current
R. Congo
BRAZIL
SOUTH
SOUTH EAST TRADE WINDS
Tropic of Capricorn
AMERICA
Brazilian Current
Calms of Capricorn
R. Orange
R. la Plata
Antarctic Current
Antarctic Circle

MAP VIII.

deflected, and divides into two branches, one flowing southwards and forming the Brazilian current, and another passing along the coast of Guiana. This latter branch, joining with the northern portion of the equatorial current, passes partly north-westwards outside the West Indian Islands, and partly into the Caribbean Sea, and thence into the Gulf of Mexico, to issue as the famous Gulf Stream. At the mouth of the gulf, termed the Strait of Florida, the Gulf Stream passes out as a strong current about 30 miles wide, with a speed of four miles an hour, a depth of 440 fathoms, a temperature above 80° F., and a deep blue colour, due to the high degree of saltness. Uniting with the portion that creeps along outside the West Indies, it flows north-east, increasing in width but diminishing in temperature, depth, and velocity. Off Newfoundland it is 320 miles wide, has a depth less than half the above, a velocity of only about one-third, and a temperature of 60° F. Near the middle of the Atlantic, about lat. 47° N., where its temperature is still 8° or 10° above the surrounding water, a division takes place. One portion flows on, or is carried by the prevailing south-westerly winds, as the **Gulf Stream Drift,** to the shores of the British Isles and North-west Europe. The other branch of the Gulf Stream turns southwards along the coast of Portugal and North-western Africa, to rejoin the northern part of the great equatorial current, thus completing a great oval whirl through the North Atlantic. In the midst of the calm waters of this whirl there is a vast area of seaweed and marine grasses, termed the **Sargasso Sea.**

A cold current from the Arctic Sea, formed by the union of branches from the east coast of Greenland and from Baffin Bay, known as the Labrador Current, passes southward between the Gulf Stream and the coast of North America, the line of separation between the two currents being known as the "Cold Wall." It disappears off Cape Hatteras, having partly sunk under the lighter water of the Gulf Stream, and having partly pierced the Gulf Stream in cold streaks.

200. **Currents of the Pacific. The Kuro-Siwo.**—From the Antarctic Ocean a cold current passes in a north-east direction to South America to form the Chili or Peru current. Gradually

Longmans & Co. London, New York, & Bombay.

MAP IX.—OCEAN CURRENTS.

becoming warmer owing to tropical heat, it turns westward about 20° S. lat., and merges into the great equatorial current of the Pacific. This last-named current, formed of a northern and southern part like the equatorial current of the Atlantic, occupies the entire width of the Torrid Zone, and is driven westwards by the trade winds to the East Indian islands. Here it is broken up into several parts, one of which passes into the Indian Ocean, while another turns southwards and carries warm water past Eastern Australia and New Zealand. The main branch, however, turns north past the Philippine Islands, and then flowing north-east, becomes the great Kuro-Siwo, or Japanese Current. The Kuro-Siwo is thus formed in a similar manner to the Gulf Stream, and resembles it in course and character. Its warm waters sweep along the eastern shores of Asia, and, after passing Japan, it divides into several branches. One of these reaches British Columbia, whose winter temperature is thus raised, just as the Gulf Stream raises that of the British Isles and North-west Europe.

201. **Currents of the Indian Ocean.**—In the Indian Ocean a cool West Australian current unites with a current that comes between Australia and Java to form a south equatorial current that flows west to the coast of Madagascar. A portion of this passes along the east of Cape Colony as the Agulhas Current. In winter, when the north-east monsoon is blowing, a north equatorial current flows westward from Sumatra, curving upwards in the Bay of Bengal, and then passing to North-east Africa, where it is turned southward. At this time also a counter equatorial current flows eastward from Zanzibar towards Java between the other two equatorial currents. In summer, during the south-west monsoon, the currents of the northern part of the Indian Ocean are reversed.

CHAPTER XVIII.

THE POLAR REGIONS AND THE ICE OF THE SEA.

202. **Arctic Ocean.**—The Arctic Ocean includes that portion of the sea surrounding the north pole, and bounded on the south by the northern coasts of Europe, Asia, and America. It does not therefore exactly coincide with the Arctic circle, which is $23\frac{1}{2}^{\circ}$ from the pole, as it reaches further south at the north of the Old World, and at the North Cape where it joins the Atlantic. With the Atlantic it has two gateways of communication, the wide opening between Norway and Greenland, and the narrower passages through Davis Strait between Greenland and the great archipelago of islands on the north of America. With the Pacific it has only a narrow connection of sixty miles at Behring Strait. The passage between the Atlantic and Pacific along the ice-encumbered channels between the islands on the northern shores of America is called the "North-west Passage," and was once much sought after as a route to India and the East. The passage along the northern shores of Europe and Asia through Behring Strait is called the "North-east Passage." This circular basin included within the above limits is but very partially known. From the parallel of 72° north, which skirts its southern land limit, up to the parallel of 80° it has been often explored, but only a few expeditions have proceeded farther north. This is on account of the sea beyond being so blocked with ice that ships are not able to make progress. In 1875 Sir George Nares reached the latitude of 80° 10′ N. in H.M.S. *Alert*, and from that ship a sledge party, under Commander Markham, succeeded in planting the British flag in latitude 83° 20′ 26″ N., 400 miles from the pole. Instead of finding the "open polar sea," the ice was found to be of most

unusual age and thickness, and to this region the name *Palæocrystic Sea*, or sea of ancient ice, has been given. Owing to the absence of land trending northward, and the polar pack not being navigable, Sir George Nares concluded that no ship could be carried north on either side of Smith's Sound beyond the position they had attained. Dr. Nansen in his famous voyage with the *Fram* (1893–1896) reached, however, a latitude of 86° 14′ N. His soundings showed a depth of over

FIG. 176.—Vessel lifted out of the water by pack-ice.

2000 fathoms in most cases, so that the deep hollow of the Atlantic passes towards the pole between Greenland and Spitzbergen.

203. **Marine Ice.**—On approaching the ice of the polar regions, its presence is indicated to the mariner by a brilliant band of yellowish-white light along the horizon called the *ice-blink*. The ice-blink is produced by the reflection of the light from the snow-covered ice. The ice of the Arctic seas is of two different kinds, the one being formed in the sea, and the other coming from the surface of land. The intense cold of the Arctic winter freezes the water on the surface of the sea, but the restless movements of the waves seldom allow a thick covering of level ice to be

formed, large stretches having an uneven surface being produced. Such an expanse of marine ice having no visible limit is called an *ice-field*. An ice-field, then, does not consist of a level sheet, but is an immense irregular expanse, having deep hollows and large mounds called "hummocks," or hills, and is often interspersed with fissures, which are sometimes filled with drifted snow. In the winter this frozen sea is kept within its narrowest limits, but at the beginning of summer the ice-field, which may be continuous for hundreds of miles, begins to break up, the smaller detached portions of a field being called *floes*, and a number of floes closely compacted together is known as *pack-ice*. It is this pack ice which so often forms a barrier impassable to ships even in summer, though at times it opens out into channels through which a bold adventurer steers. In 1806 Captain Scoresby forced his way through 250 miles of pack-ice until he reached the latitude of 81° 50′ N. A pack is sometimes broken up into loose masses called *drift ice*. The ice-fields detached from the frozen seas during the summer are carried forwards by waves and currents, and sometimes crash together with such force as to produce a scene of terrible grandeur, huge floes being broken off at the edges, and an enormous pile of fragments being squeezed together into a mass.

Many a good ship has been crumpled up like matchwood or lifted bodily on to the ice by such an icy embrace. In 1869 the *Hansa*, a German exploring vessel, was so damaged by the pressure of the ice on the east coast of Greenland that she sank. The crew with their boats and provisions established themselves on an ice-floe about two miles in diameter. For 200 days they resided on this drifting mass surrounded by other floes, and were carried southwards during the summer by the currents for a distance of 1300 miles. At this time the floe had diminished greatly in size, but fortunately an opportunity of escape to the coast then presented itself.

204. **The Ice-foot.**—There is still another form of sea ice. This is formed by the sea freezing along the margin of the land, so that a layer lifted up by the tide becomes frozen to the shore. Such a shelf of ice formed along a shore, as on the edge of North Greenland and other islands, is called the *ice-foot* (Fig. 177). The ice formed by the freezing of the Arctic seas seldom exceeds seven or eight feet in thickness, but on the coast it rises in long rugged ridges to a height of 30 or 40 feet. This shore ice not only carries loose *débris* attached underneath, but often receives a mass of stones and rubbish from the overhanging cliffs. Much of this ice-foot may remain attached to the shores for years, but during the warmth of summer the loose bergs and floes driving against it sometimes detach large masses, which float away with their load of materials. These are either carried until the ice melts and deposits its cargo of blocks and rubbish, or the floating raft of ice from the ice-belt becomes caught again in the ice of the succeeding winter.

205. **Frozen Sea Water contains very little Salt.**—During the process of freezing the sea water throws out nearly all the salts it contains, so that the ice when thawed furnishes fresh water which can be drunk.

Weyprecht observes, "When the growth of ice is carried on quickly in times of intense cold a great number of crystals are formed, whose salt particles are not only drawn downwards in the water, but scattered round on all sides. In consequence of this the original melted ice consists of crystals loosely adhering together, and mixed with the solution of salt which has been rejected from them all. As the ice grows harder by the freezing together of the separate ice-crystals, this solution also freezes with

them in its upper strata. When the latter has attained a certain degree of thickness the further formation of the lower strata progresses only very slowly. The addition of fresh ice-crystals from below goes on regularly, but in their formation the salt is almost all carried downwards into the sea."

206. **Icebergs.**—But besides the various forms of marine ice just described, there are found in the Arctic seas huge masses of ice called icebergs. These have been derived from the surface of the land in the Arctic regions, and, having been pushed down to the sea, have floated away. Nearly the whole surface of Greenland is covered with an ice-sheet which advances towards the sea, the rate of motion of the Greenland glaciers being much greater than that of Alpine glaciers, nearly 100 feet a day in summer and 30 to 35 feet a day in winter. Here immense fragments are broken off and carried by the waves and currents towards the south. The ice breaks off from one of these Arctic glaciers either

FIG. 177.—Ice-foot.

by being pushed along the bottom of the sea till it reaches such a depth that, being lighter than water, it is broken away by the upward pressure of the water, or by coming at once into deep water, when the mass is snapped off by its own weight. Fig. 179 explains the origin of icebergs by the extension of a polar glacier seaward.

Some of the largest icebergs are found in Davis Straits, and are often of enormous size. They carry boulders and smaller pieces of rock derived from the land over which they have passed, and floating southwards they often reach as far as the coast of Newfoundland. Here they melt away and deposit their load of stony rubbish on the bottom of the sea. At times icebergs from the west coast of Greenland have been known to reach latitude 36° N. before they were melted, but owing to the warm waters of the Gulf Stream the bergs from the east coast of Greenland do not reach nearly so far south. It must be noticed that an ice-floe, being a mass of

marine formation, bears no transported blocks, as icebergs do, except it be derived from the ice-foot. These floating mountains of ice drifted by polar currents constitute a source of great danger to the steamers approaching the American shores from England. Owing to the coldness of the air

FIG. 178.—A scene in the Arctic regions, showing a floating iceberg. (By permission of Messrs. Barne & Co.)

produced by so great a mass of ice, the vapour in this air is often condensed into a fog, so that the berg is only visible at a short distance.

Not only do icebergs scatter boulders and gravel over the floor of the sea, but they often ground in shallow water, furrowing and grinding up the sea bed. In this way large masses of seaweed may be loosened and sent

ating away. The large number of grounded bergs on the coast of .brador gives rise to almost continuous chill fogs during the summer. ıe visible portion of a berg is only a fraction of what is below water. he specific gravity of ice is about ·92, and the specific gravity of sea water arly 1·03. The ice being thus lighter than water floats, but being only little lighter the greater portion is submerged, only about one-ninth of ıe bulk being above water. As, however, the ice often encloses bubbles f air, a greater fraction than this may often be allowed. The actual height above and *depth* below water depend to some extent on the shape of the berg. The Arctic bergs are of all sizes, and often of the most fantastic shapes. Dr. Hayes measured one which stood 315 feet out of water, and was over three-quarters of a mile in length. Assuming that only one-seventh was above the water, such a berg would have gone aground at a depth of about half a mile. Being continually acted on by the waves and

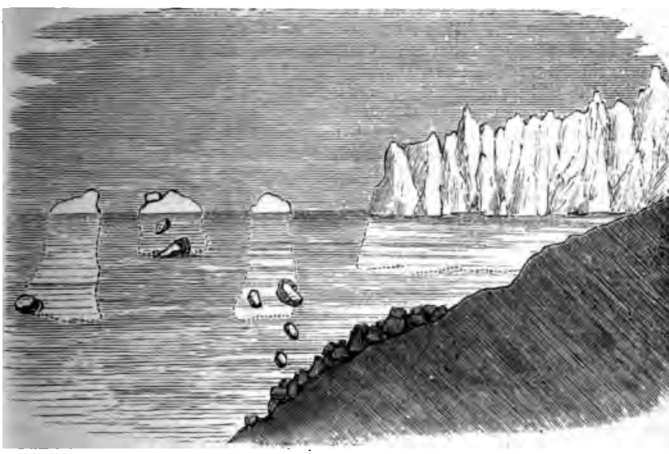


FIG. 179.—Diagram section of an Arctic glacier giving off icebergs.

the warmth, the floating bergs often fall to pieces, or, becoming top-heavy, fall over, causing great turmoil in the sea.

207. Antarctic Ocean.—The Antarctic Ocean includes the great body of water within the Antarctic Circle, and is a continuation to the south of the Atlantic, Pacific, and Indian Oceans. Compared with the district round the north pole, the south polar regions are but little known. This is partly owing to the great severity of the climate, for its temperature is generally lower than that of the corresponding latitudes of Arctic regions. South of 62½° S. lat. the temperature of both air and water is almost constantly below freezing-point even in summer. The greatest known tract of land is the line of coast stretching between the parallels of 70° and 78° S., and lying between the meridians of 160° and 167° E. long. It was called Victoria Land in 1841 by its discoverer, Sir James Ross. Ross succeeded in reaching the highest latitude yet attained in the southern seas, 78° 10′ S. His progress was then stopped by an icy barrier nearly 200 feet high,

along which he sailed for 300 miles. On this land a mountain chain was seen, in which an active volcano, 12,000 feet high, was observed. To this volcano the name "Erebus" was given, after one of the ships; while an extinct volcano to the east of this was called "Terror," after the second ship. Another explorer, named Wilkes, discovered land in 1839 between the parallels of 65° and 67° S., and extending from the 100th to the 160th meridian of east longitude. Other portions have been sighted by various navigators.

How far the land stretches is not known; but from the swarms of icebergs that are found, from the continental character of the deposits found on the sea floor, and from the diminution in the depth of the sea bed on going further south, it has been inferred that the parts observed are merely the outer portions of a large island continent surrounding the pole. Between 64° and 66° S. lat., the most southern latitude reached by the *Challenger*, depths of 1675, 1800, and 1300 fathoms were obtained; but Ross found a depth of only 260 fathoms further south, near the icy cliffs of the barrier. This Antarctic land, however, is almost inaccessible, as it is completely icebound. Only two explorers have actually landed within the Antarctic Circle, though many have seen land. But the ice in the vicinity so blocks up all approach to the coast and hides the shore, that it is difficult to say where the land begins. In some parts a line of icy cliffs 150 to 200 feet high, and called the "Ice Barrier," runs along the coast, rendering it impossible to land, whilst in other places there stretches a solid mass of ice pushed off the land, rising 5 or 6 feet above the surface, and going probably to a depth of about 40 or 45 feet below. Ross saw both these kinds of ice, the ice cliffs and the land ice, and he states that the ice cliffs ("Ice Barrier") are not found where the land is high and mountainous.

208. **Antarctic Icebergs**—Most of the icebergs met with in the south polar region are *tabular flat-topped bergs*, and are probably derived from the icy barrier already mentioned. They are often bounded by almost perpendicular sides, showing one or two stories of upright cliffs with crevasses, and having little hillocks of drifted snow on their flat tops. The entire mass shows a well-marked stratification, being composed of alternate layers of white opaque-looking, and blue more compact and transparent ice. The general mass is described as having the appearance of loaf sugar, with a slight bluish tint, excepting where fresh snow resting on the top and ledges is absolutely white.

The colouring of the crevasses, caves, and hollows is said to be a pure azure blue, so that these southern bergs are magnificent sights. The Antarctic bergs also differ from those given off by Arctic glaciers in seldom bearing any visible rocks, stones, or dirt on their surface, though it is probable that, in the lower parts of the bergs under water, gravel and other *débris* may be present. They are also met with several degrees nearer the equator than the north polar icebergs, being carried by the flow called the Antarctic Drift Current. Generally speaking, the limits are 35° S. lat. and 40° N. lat. (See Map X.).

CHAPTER XIX.

EVAPORATION AND CONDENSATION—DEW, MIST, FOG, RAIN, AND SNOW.

209. **Evaporation** is the process by which a liquid is changed into a state of vapour, and this is one of the most important effects of heat. During the process a considerable quantity of sensible heat passes into the *latent* or insensible state (par. 79), and hence evaporation has a cooling effect on the body from which the vapour rises, and the cooling is greater in proportion as the evaporation is more rapid. This heat makes its appearance again when the vapour is condensed or re-converted into a liquid. Water evaporates at all temperatures, though most rapidly during the process of boiling or ebullition (par. 77). But even snow and ice give off vapour from their surface. A piece of ice placed in the balance-pan of the scales and carefully weighed will be found to diminish in weight slowly, though the air may be below freezing point. Whatever, therefore, may be the temperature of the air, it is almost constantly receiving aqueous vapour from the surface of the water and moist ground. This evaporation is due to the heat of the sun, and is therefore most active in the equatorial regions of the earth, where the sun's rays are most powerful. This vapour rises in an invisible form and diffuses itself through the atmosphere. It really exists in the spaces between the air-particles, though it is convenient to speak of it as contained in the air. A certain quantity of air, say a cubic foot, is only capable of receiving a certain quantity of vapour at a certain temperature and pressure. If we increase the temperature or diminish the pressure, the air becomes capable of holding more vapour. At the freezing-point air *is only capable of holding* about one-tenth the quantity it holds

at 60° F., the temperature of an ordinary summer day, while air at 80° F. has nearly twice the capacity for vapour that air at 60° F. has. When air contains all the vapour that it is capable of containing at a certain temperature it is said to be *saturated*. As soon as the air which is saturated with vapour has its temperature lowered, some of the vapour is condensed and passes into the liquid form; or if the temperature be lowered below freezing-point, it will become solid.

210. **Condensation**, then, is the process by which a vapour or gas is converted into the liquid or solid form, and this process is brought about either by the application of cold or an increase of pressure. Distillation is the process of evaporation and subsequent condensation into falling drops, and is often employed by the chemist to free water from the impurities dissolved in it (see par. 6). It must be borne in mind that all distilled water, whether it be obtained by the rapid process of the chemist or by the slow process going on in nature, is pure water, the dissolved matter being all left behind. The condensation of the vapour of the air is nearly always the result of a diminution in temperature, in consequence of which the capacity of the air for water-vapour is lessened, and a portion of it is therefore thrown down. Thus, if air at 80° be saturated, and its temperature be then reduced to 60°, about one-half its vapour would be condensed during this reduction of temperature. The quantity of vapour in the air varies greatly with the seasons, the climate, the height above the sea, and various local causes. It is hardly ever completely saturated, nor ever entirely dry, and is constantly varying. The rate of evaporation is influenced by several circumstances. The larger the surface of a given quantity of water, the more rapidly does it evaporate, for, except the liquid be boiling, the evaporation takes place at the surface. Heat also increases the process, as it is well known that holding a towel before the fire dries it more quickly than leaving it exposed on a line. Wind also increases the rapidity of evaporation by bringing fresh layers of non-saturated air in contact with the wet surface. The hygrometric (Gr. *hugros*, moist) state of the air has also to be considered, for if the air be already nearly saturated, it takes up additional moisture very

slowly; while, if it is nearly dry, it takes up the moisture quickly. There is usually more aqueous vapour in the air in summer than in winter, for then the air is warmer and is capable of holding more vapour, though it may not feel so damp. As already mentioned, this aqueous vapour is chiefly found in the lower atmospheric strata, and diminishes so rapidly that at a height of five or six miles it is scarcely appreciable. The amount of aqueous vapour, or, more exactly, the relative humidity of the atmosphere, is ascertained by means of the hygrometer, already explained. The important part played by this aqueous vapour in allowing the rays from a highly heated source like the sun to pass through it freely, and in obstructing the heat-rays from a body of much lower temperature like the sun-warmed earth, has been already mentioned.

211. **Dew.**—One of the forms in which the atmosphere restores part of its vapour to the earth is dew. Dew is moisture deposited as small drops from the atmosphere without the formation of any visible cloud. Towards sunset the heat received by the earth from the sun becomes less than the heat radiated from its surface. If the sky be clear, this heat radiated from the earth passes into space and the ground becomes cool, and bodies near its surface are thus chilled. The layer of air in contact with these bodies also becomes chilled, and at last descends to a degree of temperature at which it is saturated by the aqueous vapour it contains. A further slight reduction causes the air to deposit a portion of the aqueous vapour it contains on the surfaces of the bodies previously cooled by radiation. The temperature at which dew begins to be formed is called the *dew-point*. It varies with the degree of humidity of the atmosphere. One night it might be 41° F., and next night it might be 50°, though the temperature of the air on both nights might be about the same. The nearer, however, the air is to the point of saturation the sooner will the dew-point be reached. When the dew-point is below 32° the moisture deposited passes at once into the solid state, and is known as *hoar-frost* or *rime*.

Dr. Wells's theory of the *formation* of dew just explained is quite correct; but it has been proved that the vapour, which is condensed, rises mainly from the ground instead of falling from the air above. Mr. J. Aitken carried out a number of experiments showing that the greater part of true dew is formed from the vapour that rises from the heated ground and has been trapped by grass and other cold objects. One experiment which establishes this consists in removing at sunset a portion of the turf from the ground and weighing it in a metal pan. The turf is then left in the pan and replaced so as to be in good heat-communication with the ground. After the lapse of some time the turf is again weighed, when its weight is found to be sensibly diminished. By covering the turf thus removed and replaced with a thin sheet of metal, the loss of weight is largely prevented. Similar experiments proved that from bare soil and dry earth moisture always rises during the night. Moreover, the drops seen on grass and leaves are not dew at all, but moisture exuded from the

living plant. These drops are only found at the extremities of leaf-veins, *i.e.* at the points where the veins of the leaves cut the outer edges. The true dew is distributed all over the blade as a moist film. The atmospheric conditions necessary to the copious formation of dew are set forth in the latter part of this paragraph.

Lord Kelvin holds that the protective action exerted at night on vegetation by the aqueous vapour of the atmosphere is due, not so much to its power of absorbing the heat radiated from the earth's surface, as Tyndall teaches, as to its great heat-capacity. Blades of grass and the finer parts of plants would radiate away their heat below zero-point, were it not that on still nights they are protected by the latent heat of the vapour deposited on them as dew. Their temperatures can never fall below the dew-point of the air touching them. On windy nights plants obtain heat to compensate for radiation from the air moving about among them; and on cloudy nights radiation is checked by the temperature of the clouds being near the dew-point of the lower air. "Thus, either clouds, by their counter-radiation, or wind by mixing a comparatively thick stratum of air with that next the earth, keep the grass and delicate parts of other plants from sinking to the dew-point. When there is not enough of clouds and wind to afford this degree of protection, dew begins to form, and, by preventing the temperature of any leaf or flower from sinking below the dew-point, saves them all from destruction, unless, as when hoar-frost appears, the dew-point itself is below the freezing point."

Various circumstances influence the production of dew. It is never abundant except during clear and calm nights. If the night be cloudy, the clouds reflect and radiate back the heat given off from the surface of the ground, so that the surface of the earth does not become sufficiently chilled. If the night is windy, the air near the surface is constantly being renewed, and is thus prevented from being reduced to the dew-point; though a slight wind is rather favourable than otherwise, because it gradually brings into contact with the cool surfaces fresh layers of air. Upon metallic substances, which are bad radiators, and on the hard beaten road, which quickly conducts heat from the strata beneath, little or no dew is deposited; while on blades of grass, twigs, leaves, wool, hair, and other such objects, which quickly lose the heat from their surfaces, owing to being good radiators and bad conductors, a copious deposit of dew forms. But anything that checks the radiation, as a screen above or beside the object, prevents the formation of dew. It is also evident that the deposit of dew will be greater according as the air is more nearly saturated with vapour, for then the dew-point is sooner reached. Finally, dew is usually more abundant in spring and autumn, as the differences of temperature between day and night are greater than at other seasons, and the dew-point temperature is therefore more quickly and more certainly reached.

212. **Fogs and Mist.**—It sometimes happens that the aqueous vapour throughout a large space of the atmosphere near the surface of the earth becomes condensed into minute particles of water, that remain suspended in the air. These visible particles form a kind of cloud near the surface, called fog or mist. A fog may arise when a current of warm and moist air comes into contact with water at a lower temperature, or by the intermixture of two masses of air, one of which has a lower temperature than the other. Thus a warm moist current of air passing over an iceberg may have some of its vapour precipitated as fog. The frequent fogs on the banks of Newfoundland are caused by the warm damp air that has passed over the Gulf Stream coming in contact with the cold air over the Arctic current that flows down

through Davis Strait. Fogs are also often seen in low grassy bottoms or river valleys in the morning, but these are usually dispersed during the day as soon as the heat of the sun renders the air capable of taking up the moisture that has thus been condensed out of it. A mist is very similar to a fog, but the particles of moisture of which it consists are rather larger than those of a fog.

Mr. J. Aitken has shown that the condensation of the aqueous vapour of the air, either as fog, mist, or cloud, nearly always takes place around the dust-particles, or other solid nucleus, floating in the air. Ordinary dry air has been shown to contain more than two millions of minute dust-particles in every cubic foot.

213. **Clouds.**—Clouds are merely fog or mist formed in the higher strata of the air, where, as we have seen, the temperature is lower than

FIG. 180.—Varieties of clouds.

near the surface of the earth. Mist or fog is a cloud near the earth's surface; clouds are mists at a considerable height. As the warm moist air expands, it ascends and rises into colder regions, while the very act of expansion also lowers its temperature. The height at which the clouds float in the atmosphere varies much, the average height probably being between one and two miles. The thin light clouds are seen at the greatest heights, while thick dense clouds that are heavier only exist at a small distance above the earth. Clouds are not always composed of water particles, for the light fleecy clouds that float in the higher and colder regions are composed of small ice needles. This is certainly the state, as the intense cold at such great heights, from six to ten miles, is so great that water could not exist there in the liquid state. Besides, the icy

condition of such clouds is also proved by the mode in which light is refracted in passing through them. The continually changing appearances of clouds are brought about by their movement, for they are continually descending into warmer or drier tracts of air, in which their moisture is often again dissolved.

Mr. Luke Howard has divided clouds into four chief varieties—the *nimbus*, the *stratus*, the *cumulus*, and the *cirrus*. These four kinds are shown in Fig. 180, and are indicated respectively by one, two, three, and four birds on the wing.

The Cirrus (Lat. *cirrus*, a curl) is a whitish streaky cloud, having a feathery or fibrous appearance. These clouds are often called *mares' tails*, from their shape. They only exist at great heights, and it is these clouds which are believed to consist of ice particles. A cirrus cloud is often a sign of wind or a change of weather.

The Cumulus (Lat. *cumulus*, a heap) is a rounded or hemispherical cloud, often rising from a horizontal base. Hence it is sometimes called the *woolpack* cloud. The cumulus is the cloud of day, especially in summer, and is produced by an ascending current of warm air, the vapour of which is quickly condensed. Towards evening these clouds often lessen or entirely vanish. If, however, they become more numerous, especially with cirrus clouds above, a storm of rain may be looked for.

The Stratus (Lat. *stratum*, a covering or layer) is a widely extended continuous horizontal sheet, increasing from below upwards. It is generally a fine-weather cloud, and appears low down in the evenings and early mornings of the brightest days. It is indicated in the figure by two birds.

The Nimbus (Lat. *nimbus*, a dark rain-cloud) is a rain-cloud having no particular form, but usually of a dark uniform grey tint with fringed edges. It is the cloud into which the others resolve themselves when rain falls, and is therefore sometimes called *cumulo-cirro-stratus*. Other forms exist that are brought about by a combination of some of the preceding. One of these, called cirro-cumulus, is a high cloud consisting of small irregularly placed rounded masses, like a flock of sheep lying down, or like the markings on a mackerel, from which we get the name "mackerel sky."

214. **Rain.**—Of all the forms in which the water derived from the earth by the process of evaporation is restored again to its surface, rain is the most important. It is produced by the continuous condensation of the water vapour of the air, so that the minute particles that form clouds unite to form drops, which fall to the earth through the action of gravity. At great heights the raindrops are very small, but as they fall they generally increase in size, either by several joining together or by condensing on their cool surface the aqueous vapour of the strata of air through which they fall. This explains why the drops that fall from a thick mist are so small, the mist being nearer the surface of the earth. Occasionally, however, drops falling through warm dry air may become less in size, or even be completely evaporated before reaching the earth.

215. **The Rain-gauge.**—It is important to ascertain the *amount* of rainfall that occurs at any place. This should be done every day at a fixed time, and the daily amounts in a certain year when added together will give us the annual rainfall for that year. By taking the annual amounts for a number of years, and dividing by that number, an average annual rainfall for any given place may be ascertained. The instrument used to measure the rainfall is called a Rain-gauge. A standard rain-gauge consists of a funnel emptying into a can, funnel and can being placed inside a circular copper vessel as shown in Fig. 181. The diameter of the funnel is 8 inches, so that the area of its collecting surface is 50·26 square inches.[1] One inch of rainfall, *i.e.* rain one inch deep, would therefore deposit in this rain-gauge 50·26 cub. inches of rain; half an inch of rainfall would deposit 25·13 cub. inches of rain. Now 25·13 cub. inches = $14\frac{3}{4}$ fluid ozs. If, then, $14\frac{3}{4}$ fluid ozs. be poured into a measuring glass of uniform diameter, a line at this level will represent half an inch of rain. On dividing the vessel below the line into 50 equal parts, each of these will represent $\frac{1}{100}$th inch of rainfall.

FIG. 181.—Rain-gauge and measuring glass.

By emptying the can into the measuring glass graduated as above at a certain time (9 a.m) each day, the amount of rainfall for one day can be obtained. Of course on very wet days the can might need emptying more than once, though a rainfall of 0·01 is considered a rainy day in Britain.

To avoid errors in estimating rainfall the rain-gauge should be placed in an exposed situation about one foot above the ground, its rim should be kept horizontal, and measurements should be made at least daily at a fixed time. Were more time to elapse between each measurement, the loss by evaporation would lower the quantity.

216. **Distribution of Rain.**—On the accompanying map an attempt is made by means of shading to indicate the average annual amount of rainfall on the various portions of the earth's surface, but it is not possible to indicate this accurately for all places, as our knowledge is not sufficiently complete. Still such a map is useful, and for all places where observations are regularly made it may be regarded as tolerably correct. Various circumstances affect the quantity of rain which falls in different countries. In all cases it is produced by the cooling of air more or less charged with aqueous vapour; and Mr. R. H. Scott gives us the three chief causes—"(1) The ascent of a current of damp air which is chilled by expansion as it rises. (2) The contact of damp and warm air with the cooler surface of the ground, as in the case of our west coasts in winter, where the land is colder than the sea surface. (3) The mixture of masses of hot and cold air."

The first cause comes into operation at and near the equator. There the

[1] The area of a circle = $3\frac{1}{7}$ times the square of the radius.

ARCTIC OCEAN
GREENLAND
Baffin Bay
Davis St.
NORTH AMERICA
Constant Rains
Winter Rains
NORTH
PACIFIC
Tropic of Cancer
Sandwich Is.
OCEAN
Zone of Constant Rains
accompanied
by Electrical explosions
Equator
SOUTH
Tropic of Capricorn
PACIFIC OCEAN
Arctic Circle
Iceland
Jan Mayen
Rain in all seasons
BRITISH ISLES
Limit of Icebergs
Northern Limit of Snowfall
Azores Is.
ATLANTIC
Canary Is.
C. Verde Is.
OCEAN
SOUTH AMERICA
SOUTH
ATLANTIC OCEAN
Summer Rains
Constant Rain or Snow
South Shetlands
EUROPE
Summer Rains
Rainless District
AFRICA
Autumn
Rains
Madagascar
ASIA
Summer Rains
Rainless District
Desert of Gobi
Tibet
Laccadive Is.
April to October Rains
Maldive Is.
INDIAN OCEAN
Sumatra
Tropic of Capricorn
Philippine Islands
Japan Is.
NORTH
PACIFIC
Tropic of Cancer
OCEAN
Caroline Is.
Equator
Solomon Is.
AUSTRALIA
Winter Rains
Winter
Rains
Southern Limit of Snowfall
Southern Limit of Icebergs from Antarctic Regions
Crozet Is.
Kerguelen
ANTARCTIC OCEAN
South Zone of Unperiodical Rains
Antarctic Circle
Enderby Ld.
Wilkes Land
100 Long. W. 80 of Green. 60
60 Long. E. 80 of Green. 100
MAP
Showing Mean Annual
RAINFALL OF THE EARTH
The white spaces indicate Rainless Districts and the darker the shading the heavier is the rainfall of a district. The figures indicate the average annual amount in inches

temperature is high; and as the capacity of air for moisture greatly increases as the temperature increases, the rising and expanding air in tropical regions is chilled as it ascends, and we have a region of almost constant and heavy rain, often accompanied by violent thunderstorms. Speaking generally, the annual rainfall decreases from the equator to the poles. At St. Domingo it is 107·6 inches, at Havannah it is 91·2 inches; at Madeira, 27·7; at Bordeaux, 25·8; and at London, 23·5.

The second cause of rain is that to which the wet western coasts of Europe are mainly due. In Ireland, for example, the annual rainfall on the west coast is 45 inches; and on the west coast of Britain it is about 37 inches; while the rainfall on the east side is only about 24. But both the first and second causes contribute to this result on our west coasts; for though the south-westerly winds that come across the Atlantic are charged with water vapour, some of which is condensed in the lower layers by the colder sea-coast as they pass inland, yet it must be also noted that this coast is mountainous; and as the air is forced to ascend the sides of

FIG. 182.--Condensation of moisture in air-current ascending a mountain.

the mountains it becomes rarefied and chilled, so that the higher layers of air have their moisture condensed on the seaward slopes of our western hills. Hence we find that, as a general rule, rain is more abundant on the sea-coasts than in inland regions, and more abundant in mountainous districts than in the lowland regions. The wettest place in England is at Seathwaite, near the head of Borrowdale, in Cumberland. For six years it has had an average annual rainfall of 154 inches. Lincoln is the driest place, having a mean annual rainfall of only 20 inches. Bergen, on the west coast of Norway, has a mean annual rainfall of over 80 inches. In this country the rainfall seldom exceeds an inch in a day, though occasionally it has amounted to four inches. In tropical countries, however, it is sometimes from 30 to 40 inches a day.

217. **Rainy Seasons**.—In some parts of the world the rain only falls during certain parts of the year, and these are spoken of as the *rainy seasons*. Between the tropics [1] the rains are periodical, being most abundant when the sun is vertical. When this happens close to midsummer, as it does near the tropics, there is only one rainy season; but when several weeks intervene between the times when the sun is directly overhead, as near the equator, there are two rainy seasons. In the districts where the monsoons prevail the rainy season depends on these winds. Thus in India and China, when the north-east monsoon is blowing from October to April, the east coasts receive the supply of rain; but most of the rain of India and the western coasts generally is chiefly brought by the south-west monsoons that blow from April to September. Outside the tropics, in higher latitudes, where the winds are variable, rain may occur at all seasons.

218. **Regions of Great Rainfall and Extreme Dryness**.—The regions of greatest rainfall are (1) parts of the equatorial regions of calms already described, and (2) certain districts where moisture-laden winds meet ranges of mountains and are forced to ascend. At Cherrapoongee, on the Khasia Hills, in Assam, at an elevation of more than 4000 feet above the sea, the annual rainfall is said to be 560 inches. This is due to the condensation of the vapour brought by the winds called the south-west monsoons from over the Indian Ocean. These winds on rising to this height are cooled below their dew-point, and their great moisture is thus precipitated. On the Western Ghauts, near Bombay, there is also an annual rainfall of 260 inches, due to the same cause. At Valdivia, in Southern Chili, there is a heavy rainfall, 116 inches, brought by the westerly winds which there prevail; while on the same side of the Andes near the equator, where the south-east trade-winds continually blow, there is a rainless district in Peru. As these winds blow across the continent all their water vapour is deposited, and flows back again by rivers into the Atlantic, the last traces being extracted by the eastern sides of the lofty Andes that guard the western coast. Other rainless districts are the great tract of land stretching eastward from the Sahara through Egypt and Arabia to the Persian Desert, the Desert of Gobi, the Great Salt Lake region in the United States, and a part of the Kalahari Desert in South Africa. All these places are rainless because the winds have been deprived of their vapour during their passage over sheltering high ground, and descend on the lee side as hot, dry winds. Thus the Desert of Gobi is shut off by the lofty Himalayas from receiving any of the moisture so abundantly brought to the southern slopes of these hills, and the north-east winds from the plain of Siberia are too cold to allow of any being brought by them. Even in the open ocean, in the districts exposed to the indraught of the trade-winds, which come from a colder to a warmer region, little or no rain falls. It may also be mentioned that rain is usually more abundant where vegetation is plentiful, the air being chilled by the leaves of trees and other plants. In some cases a region has been rendered dry and even barren by an unwise clearing of the forests.

---

[1] The *tropics* (Gr. *trope*, a turning) are two circles drawn round the earth parallel to the equator, at a distance of 23½ degrees on each side of it. The southern tropic, called the Tropic of Capricorn, has the sun vertically overhead on December 21. He then moves northward, and the sun is vertical at the northern tropic, called the Tropic of Cancer, on June 21. At all places between the tropics, that is, in the tropical or torrid zone, the sun is vertical twice during the year, but at places beyond the tropics the sun is never vertical. (See chapter on the Movements of the Earth.)

219. **Snow.**—We have seen how, through the condensation produced by cold, the aqueous vapour of the atmosphere may be made to change its invisible gaseous form, and become the minute liquid particles of which fogs and mist consist, and how these particles may unite to form the drops which fall as rain. If, however, the air in which a cloud is formed is below freezing-point, the tiny water particles are frozen into crystals of ice of a regular geometrical form, being either hexagonal plates or six-rayed feathery stars. Snow consists of aqueous vapour solidified into icy particles, which cohere in regular symmetrical forms, having usually six rays or six sides. A number of such crystals usually cling together and fall as snow-flakes. They may be examined by letting them fall on the sleeve of a dark coat, and viewing them through a magnifying lens. Many varieties of these snow crystals have been observed, some of which are shown in the annexed figure. They are all formed so that the angles made by the rays bear a close relation to those of a regular hexagon, viz. 60°. Their white appearance is due partly to enclosed air particles, and partly to the reflec-

FIG. 183.—Snow-crystals.

tion of light at their numerous surfaces. Examined by a lens, each little crystal is seen to consist of transparent ice.

Snow does not fall in all parts of the earth at the sea level. It is never seen, for example, between the tropics; for even if it were formed in the higher regions of the atmosphere, it would melt as it passed through the warmer strata near the sea level. A line showing the limit of snowfall at the level of the sea is traced on the map showing the distribution of rain, and from this we see that it seldom reaches the limit of 15° from the tropics, and that the limit is more remote from the equator in the Southern than in the Northern Hemisphere.

220. **Snow-line.**—But although the snow does not fall at the sea level in all parts of the world, yet it is found, owing to the diminution of temperature with increasing height, at certain elevations in all parts. The high peaks of the Andes near the equator stretch so far into the upper and colder regions of the

air, that they are perpetually covered with a snowy mantle. *The snow-line, or limit of perpetual snow, is that line below which the solar heat of summer is sufficient to melt all the snow that falls, but above which more snow falls than the heat of the summer can melt.* This line takes the form of a curve, which starts at a height of about 16,000 feet at the equator, and gradually descends to the sea level near the poles. Thus at Quito, near the equator, the limit is 15,800 feet; on the high peaks of Mexico, 14,800 feet; in Spain, 11,200 feet; on the Alps, between 8000 and 9000 feet; on Dovre Fjeld Mountains in Norway, 4000 feet; at the North Cape, only a little above 2000 feet; and at Spitzbergen, near the level of the sea. The highest mountain in Britain, Ben Nevis, 4400 feet, is a little below the snow-line, though snow may remain through some of the summers in sheltered hollows. But the height of the snow-line does not depend entirely on latitude. It varies with the character of the prevailing winds, with the greater or less dryness of the air, and with the volume of snow that falls during the year. It is lower, for instance, on the moister and warmer south slope of the Himalayas than on the far colder but drier north slope of these mountains. It is 16000 feet on the south slope, and 20,000 feet on the north slope. On the northern side of the Alps it is about 8000 feet; but on the southern side, which receives more sun and warmer winds, it is 8800 feet.

The snow which falls below the snow-line dissolves, and soon adds to the water supply of a country; but that which falls above the line produces ice-caps, névé, and glaciers, which will shortly be described. *Sleet* is a mixture of melting snow and rain. *Hail* consists of hard pellets of ice which fall through the atmosphere in showers. These pellets are sometimes simple rounded masses; sometimes they are of an irregular shape, and formed of concentric layers of ice round a core. How they are produced is not definitely known. Hailstones vary in size from a small pea to a hen's egg. In our climate they fall principally in spring and summer and often precede a storm.

221. From what has been said it will be seen that there is a continual circulation of the water of the globe. By the agency of the sun's heat immense quantities of water are continually being taken up into the atmosphere in the state of vapour. For a time this remains invisible, but by condensation it is at last brought into a visible condition as cloud or mist, and the clouds by further condensation discharge their contents chiefly as rain. It has been calculated that in our country about one-third of the rain that falls on the land is at once evaporated again, another third is

d by the rocks, and after a longer or shorter course beneath the for variable lengths of time this portion again comes to light in The other third flows off at once into the rivers, where, indeed, the water also ultimately goes. Rivers pour their contents into the sea, m the surface of both rivers and sea evaporation takes place, and the ets off on another round. Professor Dove compared the atmosphere st still, of which the sun is the fire and the sea the boiler. The cool he higher parts of the atmosphere and of the colder zones acts the a condenser, and on a wet day the liquid distils over as rain.

CHAPTER XX.

THE SCULPTURE OF THE LAND.

Action of Air, Rain, Springs, Rivers, and Glaciers on the Earth's Crust.

222. THE rocks described in a previous chapter are constantly being worn away by various destructive agents acting upon them, and the present outline of the earth's surface is not that which has always been, nor is it that which will continue. We have already pointed out how the sea is continually at work wearing back the rocks of the coast, and reducing the material broken off to a finer and finer state, and how this is carried out to some distance beyond the lowest tides. Here its work of destruction ceases, for the depths of the ocean are not disturbed by the movements of the waves on the surface. But other agents besides the sea are at work on all the exposed parts of the land surface, and it is of these agents that we shall now briefly speak. The general process by which the surfaces of rocks are broken asunder and the loosened material carried away so as to expose the parts previously covered is called *denudation* (Lat. *denudo*, I lay bare). *Erosion* (Lat. *rodo*, I gnaw) and *disintegration* are other words applied to the breaking up and crumbling of rocks, and the loose material arising from this waste is often spoken of as *débris* or *detritus*. Débris is a French word adopted into English, and means *ruins*, or *remains*; while detritus means literally *matter rubbed off*.

223. **Action of the Atmosphere.**—This has already been referred to in speaking of the "weathering" of rocks. The oxygen of the air is ever entering into new combinations with those rock constituents for which it has an affinity, and in this it is assisted by the moisture of the air, which also contains the same element. By this union of the oxygen with the different bases of rocks, changes of colour, as well as a breaking up of the

surface of the rocks, is often produced. Thus rocks containing the protoxide of iron (FeO) often have a greenish colour; but when the iron unites with more oxygen to form the sesquioxide (Fe_2O_3) the rock is disintegrated, and the new compound of iron gives a red or brown colour to the material formed. Another atmospheric influence is the varying heat at different times, the alternate expansions and contractions thus produced tending to loosen the particles on the surface of the rocks. The action of the carbonic acid of the atmosphere has been already mentioned. This compound tends to form soluble combinations with the magnesia, lime, and potash in the different varieties of felspar, and the mineral then produces the white clayey substance called kaolin (par. 118). The power of water containing CO_2 in solution to dissolve calcareous rocks has been often referred to (see par. 106).

224. **Action of Rain.**—The action of rain on the rocks of the earth's

FIG. 184.—Earth pyramids in the Tyrol.

rust is both *chemical* and *mechanical*. In passing through the air it dissolves small quantities of oxygen and carbonic acid, and after reaching the round it obtains a further supply of carbonic acid from decaying animal nd vegetable matter. How this oxygen and carbonic acid assist in disntegrating rocks has already been described, and it is this general action f the gases contained in the air or dissolved in water, assisted by the heat f the sun, and especially by *frost*, that is referred to under the word 'weathering." The loosened material on the surface of rocks produced by his "weathering" is then carried away either by the mechanical action of he rain or wind, particularly from the exposed faces of cliffs and the sides f hills. The smaller materials are carried farthest, while the larger pieces re left behind to undergo further disintegration. The softer parts of the ocks suffer most from this action of the weather and the mechanical force xerted by rain, and thus are produced irregular surfaces, the more easily ttacked portions giving rise to hollows and the harder to projecting pieces.

The natural division of the rocks into cubical masses by the joints or cracks greatly assists in this work of disintegration.

Every one has noticed the small impressions made by the raindrops on the surface of sand and mud, and it has sometimes happened that these have been preserved in the rocks for thousands of years. But more striking effects of the power of rain are often seen in the natural arches and conical pillars of earth capped by a block of stone which are found in the Tyrol, the western States of America, and other districts. These have been produced by the prolonged action of the rain. Imagine a valley or depression filled with loose earth or clay, through which blocks of stone are scattered at various depths. The pattering rain, assisted by the tiny streams that form, loosens the material and transports it to a lower level, but each block of stone protects the part it covers, so that at last when the surrounding portions are removed, a number of conical pyramids of earth remain as monuments of the extent of erosion that has been produced.

225. **Work of Rivers.**—The land area from which a river and its tributaries collect their water is called its *catchment basin;* the land which separates adjoining basins is called a *water-parting*, and the slope down which the water runs is called a *watershed.* The *source* of a river is to be found in some little rill or spring on the slopes of a hill, and the water of which it consists has descended from the clouds in the form of rain or snow. This water gathers at first into tiny rivulets, and these, as they descend, are joined by many others; a rivulet is formed, which receives many tributaries, and thus there is produced a common stream, often of great size, which carries down a huge volume of water into the sea. This may again be taken up into the air by the process of evaporation, may again form clouds, which discharge their contents on the earth, and thus the continual circulation of which we have previously spoken goes on.

226. **Valley-making.**—As an active agent in altering the surface of the earth a river effects erosion of its bed and banks, and transport of material in one part of its course, while in another part it deposits this material. In the upper part, where the fall or slope is steep, the river carries down sand and stones, the lighter and smaller particles being carried furthest. In times of flood the torrents of rushing water on a mountain slope tear up the rocks, hurling them down the stream, and making deep trenches on the mountain slopes.

In some parts of the rocky beds of rushing streams the eddies produced in the water cause a number of stones and sand-grains to revolve, and these form smooth rounded cavities called *pot-holes.* Pot-holes are often seen several feet deep. The fragments of rock torn away by the rushing waters aid in breaking off other portions, and by continual rubbing and pushing along have their sharp corners broken off, so as to become rounded into smooth pebbles.

The particles held in suspension in the water, and which settle down as it becomes stiller, are called *sediment;* and the more disturbed the water is, the larger are the particles forming the sediment. But besides acting as carriers of sediment, rivers also carry large amounts of matter *dissolved* from the rocks over which the water has run. Thus the waters of the Nile contain in solution 14 parts of mineral matter in 10,000, those of the Rhine 17, and those of the Thames 40.

Many of the great valleys of the world have been excavated by rivers. These river valleys are of various shapes, sometimes being deep and narrow, when they are called *gorges* or *ravines*, but at other times wide and comparatively shallow. The action of the flowing water is greatly assisted by

the earth and stones carried along by the stream, the running stream itself having but little abrading power. These rub against the bottom and sides of the channel, and thus carry on the work of wearing away the bed and the sides of the stream. We can thus understand the following description of Professor Green:—"Rivers are denuding tools, which tend to cut steep-sided trenches across a country; and these trenches they are con-

FIG. 185.—A cañon in the Colorado district.

tinually deepening as long as they have sufficient fall." That many river valleys have not this sharply defined appearance is due to the fact that the various other denuding agents mentioned above have been at work on the sides of the stream wearing away the rocks and widening the valleys, especially where the banks are formed of soft rock. The inclination of the

strata also assists in determining the shape of the valley. When we look at the river trenches formed in a district where rocks lie in horizontal beds, and where there is little or no rain to wear away the flanks of the river gorge, we see the above description of a river trench is true. Magnificent examples of such deep gorges worn by rivers, and called cañons, are seen in the course of the river Colorado and its tributaries. Here the main stream flows for about 300 miles through a chasm from 150 to 500 yards wide in most places, with a depth varying from 3000 to 6000 feet. On each side of this Great Cañon are numerous other cañons, at the bottom of which tributary streams either now run, or once have run. These great chasms are the result of river erosion, and have been worn out of the high and arid tableland of this marvellous region.

That these mighty gaps have been formed mainly by the action of the rivers is plainly proved by the fact that the beds on each side of the cañons correspond perfectly, and also by there being no signs of fissures or rents produced by any convulsion of the land. In some places the vertical walls of the cañons reach quite up to the tableland above; at other places

FIG. 186.—Section showing the rocks at the Falls of Niagara.
a, sandstone; *b*, shale; *c*, beds of limestone.

the walls present inclined slopes on which gigantic earth-pillars resembling towers, pinnacles, buttresses, etc., have been formed in the way previously described.

Many ravines have been formed by the slow retrocession of the waterfalls that occur in the beds of some rivers. Such has been the origin of the deep trench that stretches a distance of seven miles from Queenstown to the Niagara Falls. This ravine has a breadth varying from 200 to 400 feet, with almost perpendicular walls, which terminate suddenly in the escarpment or heights seen at Queenstown, where the falls are believed to have first been situated. On looking at the figure it will be seen that the falls take place from the edge of hard limestone rocks, and that these rocks overlie beds of shale, which is a much softer material. These soft shales are being continually crumbled away and removed by the spray that rises from the

pool at the foot. The projecting limestone thus undermined falls down at various intervals, and thus the position of the falls is continually retreating.

It is even possible to form some idea of the time taken to cut out the gorge. Recent inquiries have shown that the rate of retrocession is probably between four and five feet per annum, and if we divide the length of the gorge by four, we get between 9000 and 10,000 years as the time during which it has been forming.

227. Longitudinal and Transverse Valleys.—Mountain chains usually run in one general direction; and though they may give off lateral ridges,

FIG. 187.—Bird's-eye view of the river and falls at Niagara.

the chief peaks coincide more or less with the axis of the main chains. In several cases we find nearly parallel ranges separated by a depression or valley, whose bend coincides with the general direction of the mountain chains.

Such a valley between two parallel ranges is called a *longitudinal valley*. Thus the Rhone flows from its source in a glacier of St. Gothard to Martigny in the longitudinal valley between the Bernese Alps on the north and the Italian Alps (Lepontine and Pennine) on the south. Transverse valleys run more or less at right angles to the mountain chains. They are often deeply entrenched by the mountain torrents that run down their slopes and act as feeders of the main stream that runs in the longitudinal valley (see Fig. 188). The tops of two adjacent transverse valleys often lie between

two peaks, the depressions between which form a *col* or *pass* to the opposite side of the mountain chain. Longitudinal valleys are usually longer, have less descent and more gentle streams than transverse valleys.

FIG. 188.—Longitudinal and transverse valleys.

228. **Alluvium and River Terraces.**—When a river traverses a wide valley it may in times of flood overflow its banks, and the spreading water, losing its velocity, deposits on the tracts of land over which it extends, silt, mud, sand, and gravel, mixed at times with twigs, leaves, and bones.

The matter washed down and deposited on the sides of the river in this way is called *alluvium* (Lat. *luo*, I wash). Alluvial soils are thus formed on the districts bordering a river, and the edge of the alluvial plain is generally at the level of the highest floods. The height of this plain is at first increased by successive floods, but as the river deepens its channel the flood can no longer reach its first height, part of the old alluvium is cut into, and a new flood-plain is formed at a lower level. In this way the river valley comes to show a series of terraces formed of alluvium. These terraces of mud, sand, and gravel are often spoken of as *river terraces*. These alluvial terraces are seldom found complete on both sides of a river at the same place, as, owing to the serpentine course of many streams, the banks are often eroded on the concave side, and deposits made only on the convex lower banks (see Fig. 206).

229. **Delta Formation.**—In the lower part of the course of a river the velocity of the stream has generally become so much diminished that deposition of sediment exceeds erosion. This takes place in particular where the flow is checked by the sea or lake into which a river empties itself. Here a large part of the sand and mud is deposited, and where the tides are small and the currents feeble this accumulates, so that in time the matter thus brought down rises above the sea-level. In this way the river slowly fills up the bay or gulf into which it discharges itself, and a triangular deposit of low flat alluvial soil, called a *delta*, is formed. It is so named from its resemblance to the Greek letter Δ, delta. The delta begins at the point where the waters laden with mud first met the sea in

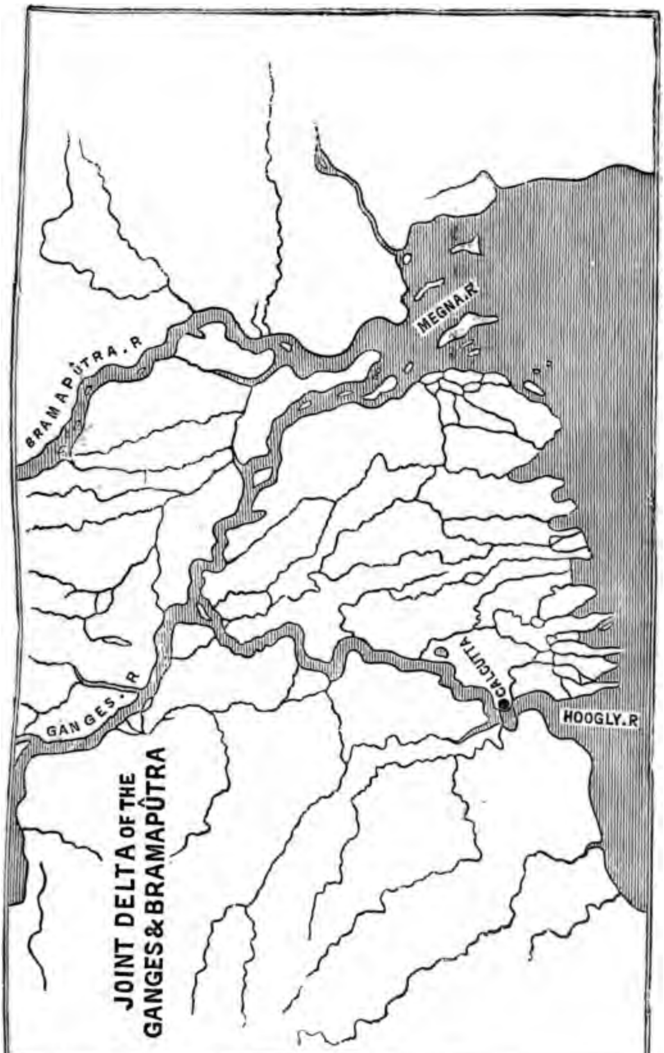

BRAMAPÛTRA. R
MEGNA. R
GANGES. R
CALCUTTA
HOOGLY. R
JOINT DELTA OF THE
GANGES & BRAMAPÛTRA

FIG. 189.

times long past; and from this point, called the *head* of the delta, it gradually widens, growing outwards and upwards year after year. It is made up of the successive layers of detritus brought down by the stream; and the shorter and more rapid the course of the river, the larger and coarser is the sediment forming this detritus. In times of flood, too, the particles will be larger than at other times. The main stream usually splits up into many branches, which traverse the accumulations brought down, and these various channels form a regular network of streams, which sometimes shift their directions, owing to some being silted up and new ones being formed. Among the well-known deltas are those of the Ganges and Brahmapûtra, the Mississippi, the Nile, the Rhine, the Rhone, and the Po. The Ganges has its source in a mountain stream issuing from a glacier in the Himalayas, at a height of 13,800 feet above the sea. During the first 200 miles of its course it falls 12,000 feet, and has almost the speed of a torrent; but after this it flows more quietly for over 1700 miles, when it discharges its waters by many branches into the Bay of Bengal. During its course it receives a vast multitude of tributaries, twelve of which are greater than the Rhine. It has been computed that the average discharge of water by this river exceeds 200,000 cubic feet per second, and during floods it is said to contain $\frac{1}{428}$ part of its weight of matter in suspension. It would thus cover with sediment an area of 2276 miles to a depth of one inch every year. The apex or head of the delta is 200 miles from the sea, and the whole delta has an area of over 8000 square miles. At Calcutta a boring has been made through the delta deposit to a depth of 481 feet without reaching the bottom. The deposit was seen to consist of sand, clay, pebble-beds, and some vegetable remains. The delta of the Ganges is joined by the delta formed by the still larger river Brahmapûtra, and the union of these two immense deltas is shown in Fig. 189. From the mouth of the main branch of the Ganges, the Hoogly River, to the mouth of the main branch of the Brahmapûtra, the Megna River, there is a sea front of 220 miles, and the area of the united deltas is nearly equal to that of Ireland. In this delta the land near the sea is mostly a swampy marsh, covered with a rich vegetation of mangroves, nipa-palms, etc.; while beyond the margin of the land for some distance there are numerous shoals and sand-banks. As more sediment is brought down the marshy sunder-bunds will rise higher and become habitable, and the shoals and sand-banks will be changed into marshy land forming a seaward extension of the delta.

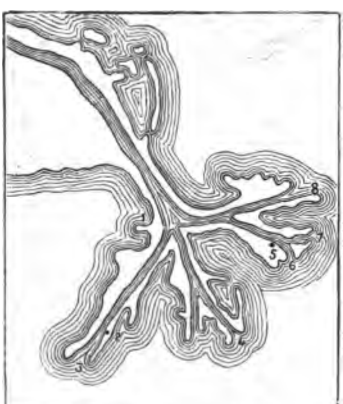


FIG. 190.—Lower portion of delta of Mississippi. 3, 4, 6, 7, and 8, channels.

The quantity of sediment brought down by the Mississippi is even greater than that brought down by the Ganges. It has long ago filled up the bay into which it first flowed, and is now sending out tongues of land into the Gulf of Mexico, and advancing at the rate of about 300 feet annually. The whole area of this delta exceeds 12,000 square miles,

of which one-third is sea-marsh. The goosefoot-like head of this delta presents a striking contrast to those of the Ganges and the Nile.

The Nile delta has the general typical form of most deltas, and the head of the delta at Cairo is 85 miles from the coast (see a map of Lower Egypt). In times of flood, which happens during the rainy season in Abyssinia and the interior, the river is charged with sediment, but owing to the annual overflow the greater part of this sediment is deposited as a thin fertilizing layer in Lower Egypt, so that comparatively little is now carried out to sea. Even that which is carried out is swept away by a Mediterranean current, so that there has been no extension of this old delta for over 2000 years.

The Rhine delta forms the greater part of Holland. For a time this river was able to deposit its sediment near the mouth without the currents taking it away, but after advancing a certain distance the movements of the sea were strong enough to remove nearly all the sediment as fast as it was brought, and but little further growth takes place. The North Sea has, ndeed, reclaimed from the Rhine delta the large space now occupied by he Zuyder Zee. The Po carries down in flood-times $\frac{1}{300}$ part by weight of olid matter, and has formed deposits that reach out into the sea for 21 niles. It is now being increased at the rate of 300 feet a year. Venice, Ravenna, and other towns stand on the delta formed by this river and the djoining streams. Wells sunk through the deposits at Venice show that ney are at least 566 feet thick. The Rhone forms a delta at its mouth which is rapidly increasing. Arles, where the river bifurcates, was 14 niles from the sea in 400 B.C. It is now 30 miles distant. The Rhone lso forms another delta, not in the sea, but in a lake through which it ows; for rivers flowing through lakes deposit a fan-shaped mass of sediment which forms a delta, the lake acting as a sieve to strain off the suspended particles travelling in the water. Thus the river Rhone enters ne Lake of Geneva as a swift and turbid stream, but on leaving it at the ther end the waters are quite blue, clear, and transparent. An ancient Roman town, now called Port Vallais, and once situated at the water's dge, is at this time more than half a mile inland. Hence the intervening lluvial tract must have been deposited during the last 1800 years.

Such a delta is called a *lacustrine* delta (Lat. *lacus*, a lake). Lakes into which rivers flow are thus being contracted at their pper ends, and are slowly eing filled up by the sediment which the river transports.

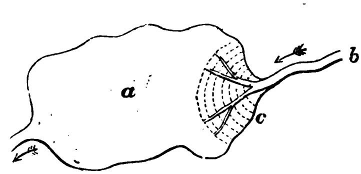


FIG. 191.—Stream running into a lake and forming a delta.

In the district occupied y the delta the sand and ilt are deposited most bundantly on the margins of the river channels, and thus the banks are raised higher han the general plain. The banks of the Po and other deltaic ivers in the lower parts of their course have been further raised rtificially in order to preserve the country from flooding. As

the river deposits on its bed, this may even rise till the level of the water is above that of the surrounding country. Should the river burst its banks great damage and destruction of property follow. Fig. 192 shows a section of a river in a delta, and is very different from that of the stream when flowing through the valley in the higher parts of its course.

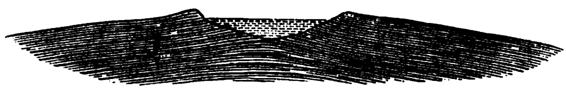


FIG. 192.--Section of river in a delta.

Every river does not form a delta at its mouth even when it brings down plenty of sediment. Where the coast-line near the mouth is steep, where the sea is deep, and the velocity of the stream great, or where there are powerful tidal currents, no delta is formed. Thus the Thames forms no delta, although it brings down every year a large quantity of sediment. Much of this is deposited near the mouth, particularly during the rise of the tide, when the downward current of the stream is arrested. But as the tide flows out it assists the river current itself in sweeping away the previous deposit. The conflicting currents in the estuary or tidal part of a river often give rise to *shoals* and *sand-banks*, the sediment being swept away in one part and gathered together in other parts. At times the ponding back of the waters by each rise of the tide in the mouth of a river causes the deposition of the sediment to take the form of a line of accumulated material across the course of the river, known as a *bar*.

230. **Springs.**—As about one-third of the water that falls as rain sinks into the ground, it is necessary to inquire what becomes of this portion. Some kinds of rocks are said to be permeable, but other kinds are almost impermeable, and the water falling on these quickly runs off the surface unless they are traversed by fissures. Among permeable rocks may be mentioned gravel, loose sand, sandstone, and chalk; whilst clay, granite, basalt, and slate are nearly impermeable. Even among those rocks which are pervious the quantity as well as the rate at which the water passes through, is very variable. In

valleys where the strata are nearly all impermeable the rainfall runs off very quickly, and gives rise to floods in rainy weather, while the rivers become dry in fine weather. Where there is a fair proportion of permeable strata through which the water can pass, an almost constant supply is furnished to the rivers. For, however deep this water may sink, either through a porous rock or through the branching fissures of other rocks, it is almost wholly stopped at last by an impermeable stratum. It then finds its way along the junction of the permeable and impermeable strata till it reaches an outlet at the surface in the form of a *spring*. Springs thus serve to drain the porous rocks that lie above them, and are always found at a lower level than the ground from which their supply of water is derived. They are met with in all parts of the world, in valleys, near the tops of hills, on the hill-sides, in caverns, and even under water. Some

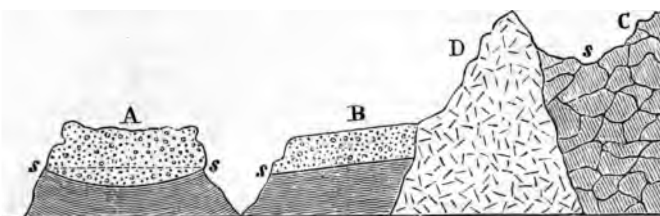


Fig. 193.—A, B, porous rocks; C, a rock with inter-ramifying fissures: *s*, *s*, surface springs; D, non-porous rock.

flow forth naturally, while others have been formed after artificial boring through the superficial strata. Where the water comes from a great depth it is warm, and as warm water can dissolve more mineral matter than cold water, such hot springs are always richer in dissolved salts than cold ones.

231. **Surface Springs.**—In surface springs the water simply falls down through the rocks by the action of gravity, and after going through its underground course comes out at the surface in some depression at the junction of a porous and impervious layer (see Fig. 193, A and B). The point at which the water flows out is often determined by the inclination or *dip* of the strata, the amount of dip being measured by the angle which the surface of the bed makes with a horizontal line. It is evident that, as the water passes through the porous rocks above, it will sink until it reaches the impermeable rocks, and then flow along in the direction of the dip or inclination until the strata come to light in a valley or the side of a hill. Hence such *surface springs* are also called *dip springs* (see s in A and B).

Of course, the upper pervious layer will only hold a certain amount of water, and when it becomes saturated to the top the water will run off at the surface.

232. **Deep-seated Springs.**—In deep-seated springs the water has sunk through the joints and crevices which are found in most rocks to a considerable depth. Then, not being able to get any lower, the pressure of the water behind and above forces it up through some fracture or fissure opening upwards till it reaches the surface. These springs may be found either in a valley, or at a considerable height on a hill. They are fed by the distant strata, and the water having passed through the cracks and fissures of its underground course comes to the surface by pressure. Thus in Fig. 193 the water that passes through the crevices of the rocks at the higher part C may pass down to a great depth; but when these rocks become full the water is forced up at the lower point *s*. Such a deep-seated spring may also rise at the junction of a water-bearing rock with a compact impervious rock.

233. **Artesian Wells.**—An important class of artificial springs or wells is known as *Artesian Wells*. Where bent pervious beds of rock lie between two bent impervious beds, so as to make a basin-shaped depression, lower in the middle than at the edges, the rain which sinks into the pervious rock where it reaches the surface will begin to gather in the central part of the porous rock as in a reservoir. If a hole be now bored in the hollow of the upper impervious bed till it reaches the water-bearing stratum, the water will well out at the top. The section

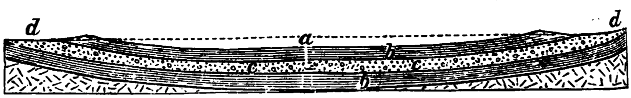


FIG. 194.—*a*, artesian well; *b*, *b*, impermeable strata; *c*, *c*, porous stratum; *d*, *d*, collecting surfaces.

shown in Fig. 194 illustrates the arrangement of strata necessary to produce such a well. The water thus obtained may have fallen a distance of many miles several months previously, and if the gathering-ground be high the issue at the well may be forced by the pressure of the water behind to a considerable height. London and Paris are both situated in such basin-like depressions. Some of the water in London is obtained by boring through the upper layer of what is called London clay till the Tertiary sand or chalk is reached. When such water-bearing strata are not tapped artificially the water will at last overflow as a natural spring. It has been calculated that the water which falls on the chalk hills in Hertfordshire takes about

sixteen months to travel to its outlet in the springs that feed the river Lea.

234. **Thermal and Mineral Springs.**—Springs of heated water are known as thermal springs. Springs which hold an unusual quantity of mineral matter in solution are called mineral springs. Ordinary spring water contains from 60 to 500 parts of mineral matter in 1,000,000. As thermal springs usually contain dissolved in them mineral substances not held in solution by springs of cold water, they are generally mineral springs also. The temperature of such springs depends on the depth from which the waters rise. There is a boring near Berlin to a depth of 4172 feet, and the water which rises has a temperature of 110° F. As several natural springs have a much higher temperature, we may assume that they rise from a still greater depth. Thus the waters at Carlsbad have a temperature of 150° F. Mineral springs are of several kinds :—

(1) Those having in solution an oxide of iron and possessing an inky taste are known as *ferruginous* or *chalybeate* springs.

(2) *Calcareous* springs, which are abundant in limestone and chalk districts, are those which have dissolved much carbonate of lime (see par. 137).

(3) *Brine* springs contain a large proportion of common salt in solution. They occur at Nantwich, Droitwich, etc.

FIG. 195.—Diagram-section (after Prestwich) showing how a spring may rise beneath water. A, fissured rocks allowing water to percolate into the channels, *c, c, c*; *p*, point where the channels come to the surface of the rock beneath the water ; *s*, spring rising through water.

235. **Submarine Springs.**—It is not difficult to see how in certain circumstances a spring of water may occur in the bed of a river, or even beneath the surface of the sea. Submarine springs of fresh water are found

on several parts of the Mediterranean coast. Where the coast is high and the rocks are fissured in such a way that the orifice of escape is beneath the sea, the pressure of the water at the higher levels may be so great as to drive out the fresh water into the sea-bed. Owing to its lighter specific gravity, as well as to the force of ejection, the water of such a spring rises to the surface (see Fig. 195).

236. **Intermittent Springs.**—Some springs are met with whose flow is discontinued for a time and then begins again. These intervals are of various duration, and seem to depend chiefly on the amount of rain. The phenomenon is easily understood on reference to Fig. 196. Here we see a subterranean cavity, which may have arisen either by the solvent action of the water or in consequence of some violent disturbance. It is fed by a number of fissures in the overlying rock, and the channel of escape is seen to curve upwards. As long as this underground reservoir is filled to the height of the bend by which the water escapes, the spring seen at the foot of the rock continues to flow; but when a time of drought comes the water in the reservoir is drained off by siphon action, and the flow ceases.

FIG. 196.—Intermittent spring.

237. **Landslips.**—It occasionally happens that large masses of rock slide down a hill or mountain into a valley, or on to a sea-coast. In such cases the strata are usually inclined towards the direction of the falling mass. This slips down because the action of the underground water has removed or rendered soft and slippery the supporting stratum, and hence the overlying portion slides forward and tumbles down. Such calamities often happen after a rainy season in mountainous districts where porous beds, such as sandstone or conglomerate, rest on sloping beds of impervious clay. The great fall from the Rossberg mountain in Switzerland on September 2, 1806, was brought about owing to the support of some upper beds being removed after a long period of rain. An immense mass of rock slipped down into the plain of Goldau, destroyed two villages, and killed 800 persons. A large landslip took place at Axmouth, on the Dorsetshire coast, in 1839. This was caused by the springs that issue from the face of the cliffs gradually removing the support of the upper part of the cliffs, so that the superincumbent mass fell forward towards the sea.

238. **Geysers.**—Geysers are hot springs which are chiefly found in volcanic districts, and which shoot up columns of water at various intervals. These intermittent jets sometimes rise to a height of two hundred feet. The Yellowstone Park in the Rocky Mountains is the most remarkable geyser region in the world. The great Beehive Geyser discharges a column once a day, while others play almost every hour. Iceland is another well-known geyser region. All the geyser waters hold in solution a considerable quantity of silica. The highly heated water decomposes the

and other volcanic rocks, and becoming slightly alkaline with the r potash these contain, it is enabled to form a silicious solution. ilica taken up is deposited again round the mouth of the orifice. plants termed algæ are known to live in the hot water, and to aid wing down the silica from solution to form the sinter deposits (par.

e cause of the periodical eruptions is probably to be found in the l increase of heat with the depth of the tube. In the middle and parts the temperature is far above the boiling-point (212° F.) at the ry pressure. But at last the lower portion rises to a position where

FIG. 197.—The Giant Geyser, United States.

mperature is above the boiling-point at the pressure it there sustains, en, flashing into steam, it hurls the column above into the air. After g for a few minutes the water falls back into the basin, and remains or a time.

39. **Glaciers.**—The snow which falls above the snow-line disappears through evaporation from its surface, and partly

by melting, but as the supply far exceeds the waste, it tends to accumulate. On attaining a certain depth its own weight is sufficient to press the lower portions into ice, and this change into ice is also brought about by the water that forms during the heat of midday sinking through the crevices of the mass and freezing at night. Successive layers are formed as each winter's snowfall succeeds another, and a semi-compact granular mass of

FIG. 198.—Glacier landscape, showing the origin in distant snow-fields and the river flowing out from the archway of ice at the end. On the surface are seen great fissures (crevasses), lines of rubbish (moraines), and a pillar of ice capped by a block of stone (glacier table). In the foreground are shown ice-worn hummocks of rock (*roches moutonnées*) and transported blocks of stone.

ice forms at the upper cup-shaped end of a mountain valley. The beds of snow accumulated by each winter's fall form layers of irregular thickness, being usually separated by a dirt-line, consisting of dust and fine grit that has been blown on to the surface in summer. When a sufficient depth of such snow-derived ice has collected, the lower portions are squeezed out and, impelled by gravity and the pressure behind, travel down

the valley slope as a *river of ice*, or *glacier*. This compacted parent mass of snow-ice is called *névé*, or *firn*, and it only gathers where there is a suitable cup-shaped expansion at the head of a mountain valley that reaches up to the snow-fields. On conical mountains with very steep sides the snow does not gather, but soon falls down to the foot, where it is melted. Hence a glacier may be described as a stream of ice formed by the consolidation through pressure of mountain snow. From the sides of steep mountains masses of snow sometimes slide down suddenly, and, accumulating as they descend, cause great destruction in the valleys below. Such falling masses are called *avalanches*.

240. **Motion and Size of Glaciers.**—A glacier fills up its valley to a certain height, and accommodates itself to the various windings. It moves slowly down, being pushed on from above, partly by sliding and partly by a yielding in the mass itself. Professor Tyndall attributes this yielding to continual fracture and regelation in the mass, but Forbes maintained that ice behaves like a very viscous fluid, the glacier being a plastic mass with tenacity sufficient to mould itself upon the obstacles which it encounters, except where the forces are so violent as to produce fissures. As mountain valleys often lead into one another, several glaciers may unite in a single

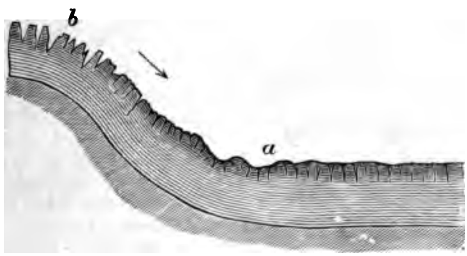


FIG. 199.—Longitudinal section of a glacier, showing large crevasses at *b* on the steep slope.

valley to form one large trunk glacier. The rate at which a glacier moves varies with the season and slope, the motion being less in winter than in summer. The motion, too, is greater at the centre than at the side, greater in its upper than in its lower surface. In this respect it exactly resembles the flow of a river. The motion has been *proved* by driving a straight row of stakes across a glacier, and observing these in the following year. They were all found to have moved down, but those nearest the middle had moved farthest, and the stakes thus presented the form of a curve (Fig. 201). Some glaciers, where the slope is slight, only move three or four inches a day; in other cases a rate of from three to four feet

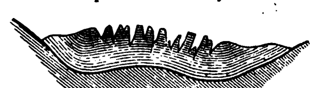


FIG. 200.—Cross-section of a glacier.

a day has been observed. Greenland glaciers have a still greater rate of motion (par. 206). The varying rate of the motion of the ice in different parts of the glacier, and the irregularities of its bed, cause strains in the ice, by which fissures or *crevasses* are produced. Some of these crevasses are of immense size, especially where there is a sudden descent in the bed of the glacier, and the ice falls over the summit of a slope. Hence the surface of a glacier is seldom even, but has the appearance of broken and irregular blocks confusedly heaped together. A Swiss Glacier varies in length from 5 to 16 miles, in breadth from ¼ to 3 miles, and in depth from 500 to 1,000 feet. The huge Baltoro Glacier, fed by the névé of the Korakoram Mountain, is 36 miles long. But even this is exceeded by the Arctic glaciers which cover Greenland, and which give origin to icebergs as already explained. The Norwegian glaciers are mostly shorter than the larger Swiss glaciers. As the glacier is pushed down the valley it is constantly being lessened by evaporation and liquefaction, but the pressure of the mass behind usually causes the compact ice to descend below the snow-line, sometimes to a distance of 5000 feet. It ends as a broken cliff of ice, with an archway from which flows a stream of muddy water. During periods when the snowfall on the height is less than usual, or when the summer heat is unusually great, the foot of the glacier retreats. Most of the Swiss glaciers are thus falling back somewhat, and this seems to point to some change of climate.

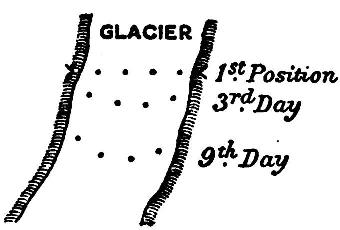


FIG. 201.—Illustrating the motion of a glacier by the changing position of stakes driven into the ice.

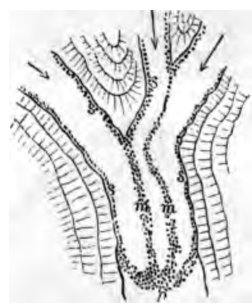


FIG. 202.—Plan showing position of moraines. *s*, *s*, lateral moraines; *m*, *m*, middle moraines; *p*, terminal moraines.

241. **Moraines.**—The sides of the steep rocky valleys through which the glacier descends are constantly being acted upon by the weather, and angular fragments of rock frequently fall on the sides of the glaciers. These form what are called the *lateral* or *side moraines*.

When two glaciers unite to form one stream, two of the lateral moraines unite and descend along the centre, forming what is called a *medial* or *central moraine* (see Fig. 202). Both the lateral and medial moraines are transported along the surface of the glacier to where it terminates, and there the

mass of stones and rubbish is discharged, forming in front of the glacier what is called a *terminal moraine.* In this way hundreds of tons of rocks, some of which have been borne on the back of the glacier for many miles, are gathered together. The surface of the glacier is constantly decreasing by evaporation and the sun's heat, and thus in summer streams of water pour into the crevasses, and flow along beneath the surface till they reach the foot. In some parts a block of stone prevents the melting of the ice beneath it, so that there a column of ice forms having a stone cap. This is known as a *glacier table.*

242. **Erosion of Rocks by Glaciers.**—Not only does the glacier carry down numerous rock-masses on its surface, but others, called the *moraine profonde*, are pushed along beneath the glacier, finally forming part of the terminal moraine. Many of these have fallen from the surface into crevasses at the sides or in the middle of the glacier. On emerging at the end they show an appearance very different from the angular fragments that are deposited from the lateral and medial moraines. While beneath the surface and held in by ice they have been subjected to great friction on the bottom or sides of the rocky glacier-bed. All their corners and projections are worn off, and their surfaces have a smooth and polished appearance. They have been ground against the underlying rocks, and have in their turn grooved and scratched the rocks over which they have passed, the marks of this scratching being known as *striæ* (Fig. 208). In this polishing and marking of the rocks the fine sand and silt resulting from the wear acts like emery powder in polishing the exposed surfaces. On the bed of the glacier are found smooth rounded rocks, known from their appearance as *roches moutonnées* (sheep-rocks). The dome-shaped *roches moutonnées* have usually a smooth and rough side, the smooth slope being in the direction from which the ice travels; while other *roches moutonnées* are rounded, striated, and polished on all sides. Such *roches moutonnées* are to be seen when the foot of a glacier retreats during a hot season, or they may be found exposed on what was once the bed of an ancient glacier.

In the bed of a glacier, hollow rounded cavities called *moulins*, or *glacier-mills*, are drilled out where a stream of water, derived from the melted ice of the upper surface, descends through a crevasse. Such little rivulets frequently form and fall down with a loud roar. As the supply of water is cut off by a fresh crack a new moulin is formed. Some of these streams scoop out in the solid rock a moulin many feet deep.

243. **Glacier Waters.**—The turbid water issuing from the cavity at the foot of a glacier has been partly derived from the melting that has taken place all along the surface, partly from the melting at the bottom of the bed due to friction, and partly, it may be, from springs. It has always a peculiar milky appearance, due to the light grey sediment in suspension. The impalpable powder that forms this sediment is one of the products of the enormous grinding that goes on underneath

the ice-mass, and its fineness keeps it from falling down until the river has reached the lower and quieter part of its course. Some of the sediment of the Rhine Glacier may be found deposited on the flats of Holland. When deposited this silt forms a kind of bluish-grey loam or clay. Rivers which take their rise in glaciers are always fuller and more turbulent towards the end of summer than at other times, as then the greatest amount of ice is melted. In winter the flow from the foot of the glacier is at its minimum.

244. **Ancient Glaciers.**—As the rocks over which glaciers pass are so distinctly marked, and as the transported material is so great, it is plain

FIG. 203.—*Roches moutonnées* and perched blocks.

that any old glaciers that have disappeared will have left marks and relics that may be easily recognised. Polished rocks and moraines of former glaciers can be seen in many parts of the lower Swiss valleys, and in several countries of Europe, Asia, and America, where no glaciers are now found. Moraine matter, striated and planed rocks, may even be found in the valleys of Snowdon and Cumberland, and the morainic matter from old British glaciers is scattered over many parts of our country, and is known as Boulder Clay. Long before history begins the valleys of Britain were filled with glaciers, thus showing that the climate of our country was once very different. Rounded sheep-rocks (*roches moutonnées*) may be easily found in the Lake district and various parts of Scotland. The former enormous extent of glaciers is also proved by the numerous transported blocks. Their huge size, their angular corners, and their difference from the rocks on which they are found, all afford evidence that they have been carried into their present position by ice. These detached masses were left by the ice on the surface of other rocks, often on the summit or edges, and are known as *perched blocks*. They are well seen in the Pass of Llanberis, on the sides

of Snowdon. (The word *boulder* is generally restricted to large water-worn rounded masses of stone, or to the more or less ice-worn blocks found in the stony clay called Boulder Clay.)

245. **Glacières.**—This word must not be confounded with glaciers. Glacières are ice-caverns, or caves full of ice. They occur unconnected with any glaciers, and are found in certain districts where a cold current of air enters a hollow cavity, and where ice is formed in winter which is not melted by the warmth of summer, though the temperature of the cave may

Fig. 204.—View from central moraine of a glacier.

then be above freezing-point. A remarkable glacière is found at Dobschau, in Hungary; others are found in various parts of the Alps, and in Iceland.

Fig. 205.—Dyke of igneous rock laid bare by denudation.

246. **General Results of Denudation.** — The general tendency of the various denuding agents is to crumble away rocks and to carry the *dèbris* from higher to lower levels. In this way lakes are filled up and disappear, the sea bottom is covered with layers of sediment, and material is

FIG. 206.—River terraces. 1, 2, levels at which the river was flowing when the upper and seco[nd] terraces were formed respectively; R, the present position of the river. The dotted porti[ons] represent material brought by the river.

FIG. 207.—The stacks of Duncansby. Evidence of waste of coast. (Wilson.)

FIG. 208.—Striated block, or scratched stone from a glacial deposit.

thus accumulated that will afterwards be consolidated into rocks. But in doing so the various denuding agents act unequally. In one place the land is eroded or eaten away at a comparatively great rate; in another place some of the denuding agents are absent, or their power is checked by the hardness of the rock, and little waste goes on. Various inequalities of outline are thus produced on the surface of the earth. Table-lands are carved out into valleys and hills, ravines are deepened and widened, and mountains are rendered more rugged and precipitous. Some idea of the tremendous amount of waste and the vast periods of time may be formed when it is pointed out that nearly the whole of the present scenery of Scotland, its mountains and glens, its uplands and lowlands, are mainly the result of the denuding tools that have sculptured its present surface. The level of the basin of the Ganges is being lowered at the rate of one foot in 2400 years, while in the case of the Po the rate is one foot in 730 years. Professor Geikie calculates that the rate of denudation in the British Isles is one inch in 800 years, and that it would require 5,500,000 years before the land was reduced to the level of the sea. But while this crumbling of the rocks and dispersion and deposition of the material removed have been going on, other changes have been occurring which tend to counteract the levelling produced by denudation. For though the land is slowly sinking in some areas, upheaval is taking place over large tracts; and volcanic activity, at one time much greater than now, frequently throws up immense quantities of matter in floods of lava or showers of ashes. There is thus a constant struggle between the two opposing forces, denudation and upheaval.

247. **Representation of the Surface of the Earth on Maps.** —For a considerable period officials of our Government have been engaged in making a National Survey of the United Kingdom, and the results of their labours are embodied from time to time in reports and maps. These maps are on various scales.[1] The General Map of the kingdom is published in

[1] A catalogue of the various maps and plans published by the Ordnance Survey may be obtained through a bookseller.

sheets, and is on the scale of one inch to the mile; that is, it is $\frac{1}{63,360}$ of the natural scale, there being 63,360 inches in a mile: in other words, one inch in length represents a distance of one mile, and one square inch represents one square mile. The county maps, which may also be obtained in suitable sheets, are on the scale of six inches to the mile, or $\frac{1}{10,560}$ of the natural scale. Parish maps and plans of towns are on a still larger scale. Besides showing the rivers, canals, railways, bridges, turnpike roads, etc., most of these maps show *relief*, that is, the undulations or surface elevations of the country, either by means of *contour lines* or by *hachures*. *A contour line is a line passing through all places which are at the same height above the sea-level.* The sea margin at a certain state of tide is taken as the datum level, and may be regarded as the contour line of no elevation. Imagine a mountainous island, and suppose the water to rise a certain height, say 50 feet. A new water-level would be formed "encroaching more on the land than the former; encroaching most at places where the beach has the gentlest slope, not encroaching at all on a perpendicular cliff, and thrust out (seawards) from an overhanging cliff." We should thus obtain a new contour line of 50 feet elevation. By supposing a gradual rise of the sea we should obtain a series of curved contour lines which would finally close in over the highest peak. The engineers of the survey obtain their levels for these *contours*, or "lines of equal altitude," by means of surveying, and do not require the imaginary floods which we have supposed. Contour lines may be drawn at any intervals, but those generally chosen are intervals of 50 or 100 feet of additional elevation above the sea-level. Lieut.-Colonel T. P. White, R.E., the executive officer of the survey, states in his little book entitled "The Ordnance Survey of the United Kingdom" [1]—

"These contours are given on our one-inch map to the highest altitudes, and, excepting for some of the uncultivated and mountainous tracts of Scotland, also on the six-inch maps, up to 1000 feet, but not (save in a very few special cases) on any of the other scales. The procedure of the survey has,

[1] Blackwood and Sons. 1886.

however, varied in this matter. In Lancashire the contours were shown on the six-inch map as close as 25 feet (vertical) apart, both in the high and low ground, and at the same interval in Yorkshire, up to the limit of 1200 feet: above that limit the Yorkshire contours were given at every 50 feet of elevation. The contours are of the greatest value to engineers and others for laying out railways, roads, canals, water-leads, drainage, etc., and for constructing ground-sections to illustrate a par-

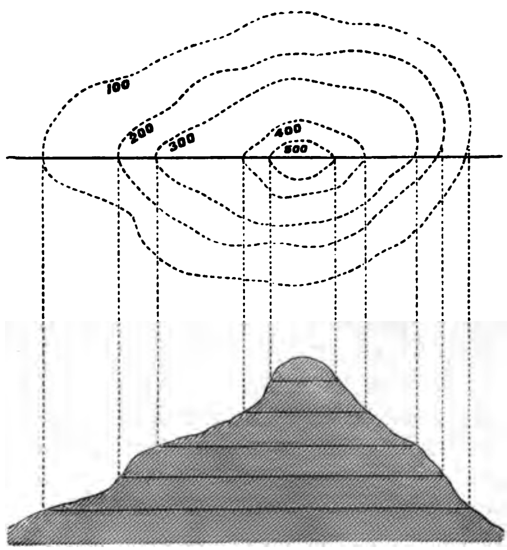


FIG. 209.—Contour lines round a hill.

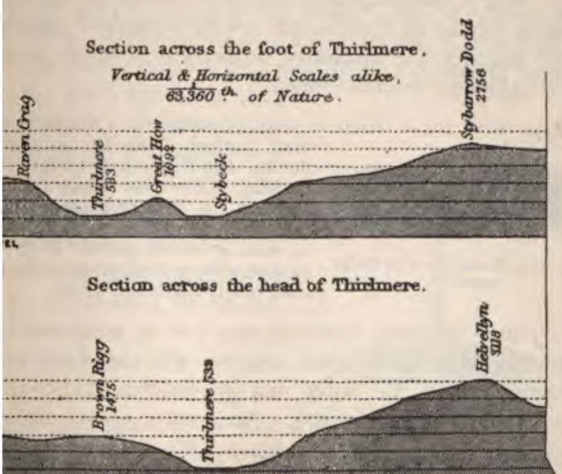
ticular line of country. 'They also form an admirable basis for hill-sketching, and for correctly expressing to the eye the surface of a country.'"

Where the ground has a gentle slope the contours spread out, and where it is steep they come close together. The shortest line drawn to the nearest contour line will give the line of steepest slope, or the *stream-line*, as it is called; and the *gradient*, or amount of rise in a horizontal foot, is inversely as the distance in that direction between successive contour lines.

Knowing their distance apart we can easily tell by means of these contours the height of any particular part above or below another, and can also picture to ourselves the slope of the ground. Figures are often attached to the dotted contour lines on the maps of the Ordnance survey. If we had a hill shaped like a right cone, there would be uniform steepness throughout, and the concentric circles representing the contour lines would be at equal distances. In a hemispherical hill the lines would be close together at the boundary of the hill, and would spread out greatly near the top. The reader may make the water-level experiment with a good-sized round orange, half of which may be placed in a flat-bottomed dish, and water poured in to successive equal vertical heights. The annexed figure shows the contour lines round a hill at successive intervals of 100 feet. The hill, however, can only be shown in section, but the inequalities of slope on the sides not seen may be judged of from the shape of the different contours.

The other method employed to represent the surface of the ground is by what are termed *hachures*. Hachures are shading lines, and these lines are made thicker and closer the steeper the ground is. This shading of the hill-features on the one-inch maps is executed on the principle "that the eye, in looking at the map, should be drawn at once to the highest summits by the emphasising of the shading there, and be able to distinguish the intermediate heights down to the lowest ground by the relative strength of the shade. Another mode of showing the relief of a district is by giving ideal *sections* across various parts. The map annexed shows the contour lines and hachures of a part of the Thirlmere Valley, in Westmoreland, and two sections of the valley are added.

AP XI.—Map of Thirlmere Valley, showing Contours and Hachures.



CHAPTER XXI.

TERRESTRIAL MAGNETISM.

248. **Magnets.**—In Scandinavia and America an iron ore having a composition represented by the formula Fe_3O_4 is found, and from it iron of excellent quality is obtained. This ore in its natural state possesses the peculiar property of attracting to it and supporting iron and some other substances, and when suspended so that it can turn freely it always sets itself in a nearly north and south line. It is often called magnetic oxide of iron, or the lodestone (A.S. *lædan*, to lead). Magnetic iron ore was first found in Magnesia in Asia Minor, and was called by the Greeks *magnes*, whence our word "magnet." *Magnets* are substances that possess the property of attracting iron, and *magnetism* is the name given to this attractive power. The ore itself, being a natural product, is called a *natural magnet*. When a bar or needle of steel is rubbed by a piece of magnetic ore it also acquires the attractive property of the ore, and such a bar is called an *artificial magnet*.

Experiment 104.—Obtain a piece of lodestone. Notice that it is a hard, blackish, stone-like body of irregular shape. Dip it into iron filings. On withdrawing it note that filings are held to it, but that the attractive force of the stone is not evenly distributed, since the filings cling in tufts to certain parts. If carefully suspended with a piece of raw silk, it will set itself nearly north and south.

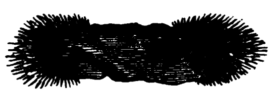


FIG. 210.—Loadstone with filings attached.

Natural magnets, however, are not as convenient for experiments as artificial ones, and we will, therefore, show how the properties of the latter may be examined, and afterwards learn how one may be made. Artificial magnets are made of hard steel that has been rubbed with a lodestone, or with

another artificial magnet, or which have been magnetized electrically.

249. **Poles and Neutral Line of a Magnet.**—A convenient form of artificial magnet to make experiments with is a magnetized steel bar. On dipping such a bar magnet into iron filings we again notice that the attractive force is not evenly distributed. Tufts of filings cling to the end of the bar, and the number of attracted filings diminishes towards the middle,

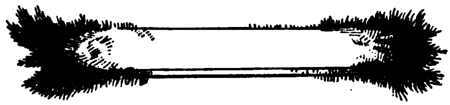


FIG. 211.

where none are found. That part of the bar where there is no visible attractive force is called the *equator* or *neutral line*, and the points near the ends of the bar, where the force of attraction is greatest, are called the *poles*. The poles, therefore, are the two points about which the magnetic force of a magnet is the most intense. The line joining these points is called the *magnetic axis* of the magnet.

A bar of steel may be bent into a curve like a horseshoe, the poles still remaining near the end, and the neutral line being still in the middle. Every magnet has two poles and a neutral line. There is no isolated pole, for if a magnet is broken in two, each part will be found to be a complete magnet with its two poles and its neutral line. In fact, it is believed that every molecule of a magnet is a complete magnet each with its north and south pole.

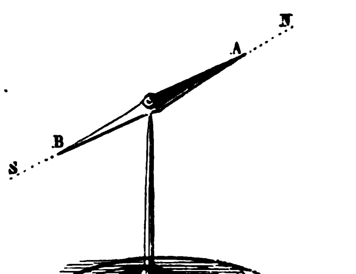


FIG. [illegible]—Magnetic needle.

250. **Magnetic Needles.**—A magnetized steel bar freely suspended at its centre, or freely balanced on a pivot at its centre, is called a *magnetic needle*. Such a bar is generally a light strip of steel shaped as in the figure, AB. When supported so that it can turn horizontally, it

sets itself so as to point with one end towards the north and the other towards the south. If the needle be turned in another direction, it always comes back to this position when free to move. This may be further shown by placing a light magnetic needle on a flat cork floating in water, for such a floating needle sets itself north and south. The end which points towards the north is called the North Pole of the magnet, or the "north-seeking pole;" the end which points towards the south is called the South Pole, or the "south-seeking pole." The north end of a magnet is often stamped with the letter N, or coloured.

251. **Magnetic Attraction and Repulsion.**—When we place the poles of a magnet one after the other in iron filings they

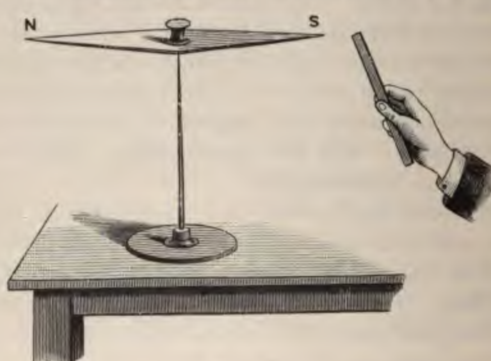


FIG. 213.

appear to have similar properties, as each attracts the filings equally well. But this is not the case, for if we present each of the poles of the bar magnet in turn to one of the poles of a magnetic needle, they affect the latter differently. If we place the north pole of the bar magnet near the north pole of a magnetic needle the latter is repelled; while, if we place the north pole near the south pole, the latter is attracted. A similar experiment by presenting the south pole of the bar magnet to the poles of the needle gives a similar result, that is—*like* poles *repel* and *unlike* poles *attract* one another. This is generally called the first law of magnetism. Hence we see

at while each magnet has two poles alike in their power of :tracting iron, yet they differ in their action on the poles of nother magnet. This law may ılso be proved by placing the magnet needle over the neutral line of a bar magnet, when the poles of the needle eventually come to rest over the opposite poles of the bar magnet, because the similar poles repel one another and the dissimilar poles attract.

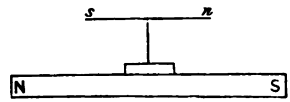


FIG. 214.

The student who has not got a magnetic needle may easily make one for himself, and verify some of the above facts by the following experiments :—

Experiment 105.—Take an ordinary knitting-needle, and laying it flat on the bench, stroke it with one pole of a bar magnet several times, always beginning at the same end. In this way the needle will become magnetized. Dip it into iron filings to show where the poles of the magnetized knitting-needle are approximately situ-ıted. To determine which is he N. pole, make a paper tirrup by doubling a short trip of paper and fastening he free end by a thread of ıntwisted silk, the other end of the thread being attached to some support as in the figure. Place the needle in the stirrup, and let it come to rest. Mark in some way, *e.g.* with a file, that end which sets itself pointing north. In a similar way, magnetize and determine the poles of another knitting-needle. Bring the poles of the second needle in turn to the poles of the suspended needle, and observe the effects. That the attraction between two unlike poles or the repulsion between two like poles is mutual may be proved by suspending both needles, and bringing their north or their south poles together. Notice that the two poles repel each other. Now put opposite poles together, when it will be found that both are attracted to each other. As a rule, only one magnet is free to move, and hence this mutual action is not seen. By bringing a piece of iron to the needle it can be shown that not only does a magnet attract iron, but iron a magnet.

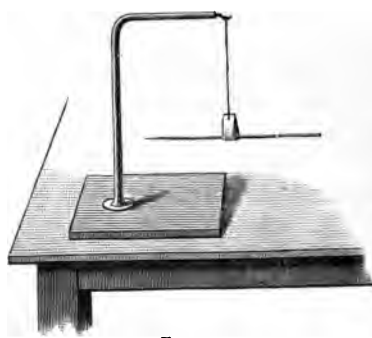


FIG. 215.

The strength of a magnet's attractive power is greatest at each end, and diminishes rapidly as we move towards its middle point, where it is *nil.*

Experiment 106.—Hang a nail of soft iron M on to the hook of a spring balance. Lay a bar magnet NS on the table, and allow the nail head to rest on the bar magnet at different places in turn, beginning at one of the poles and gradually approaching the other. At each place slowly pull the spring balance away from the magnet, and notice the pull it registers when the attraction of the magnet for the iron nail is overcome, and the nail leaves the magnet. You will find that the force grows rapidly less as the nail approaches the middle of the magnet where the force required to detach the nail is practically nothing.

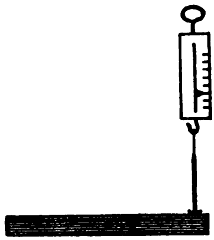


Fig. 216.

It is clear, also, that if the unlike poles of two magnets of equal strength be brought together, the magnetism of these two poles will be neutralized, and iron would be unaffected at their meeting-point.

252. **The Magnetic Field of a Magnet.**—We have already seen that a magnet can attract iron or affect another magnet, even when the two are at some distance apart. If, however, the distance between them is gradually increased, the magnet's power of attraction and repulsion becomes rapidly less and less, until it ceases to be affected. Every magnet has, therefore, a certain space surrounding it in all directions in which it can exert its influence. This region is known as the Magnetic Field of that magnet. *The magnetic field of a magnet is, therefore, the space surrounding it on all sides through which it exerts its magnetic power.* A magnetic field, and its lines of force, may be examined in an easy way by means of iron filings. In a magnetic field forces are at work which tend to move the poles of any small magnets that may be in the field along certain lines called *lines of force.*

Experiment 107.—Place a bar magnet on a table, and support a large piece of paper or cardboard just above the magnet. Over the paper loosely and evenly sprinkle fine iron filings through a piece of muslin, and then gently tap the paper with a lead pencil. Notice that the magnet exerts its influence even through the paper or cardboard, and that the filings are setting themselves in definite curves as shown in Fig. 217. These curves indicate the *lines of force* of the magnet, and therefore the direction in which a small compass needle would set itself at any particular point of the field. In fact, these lines of force can be obtained in this way by following up the direction in which a compass needle sets itself when placed at any point in the field. If a circle be drawn on the sheet of paper on which the filings

are to be sprinkled, having its centre at the centre of the magnet, and a diameter somewhat greater than the length of the magnet, the direction of the lines of force at a number of points on the circle as indicated by the filings may be marked. Now take a very small compass needle, such as is

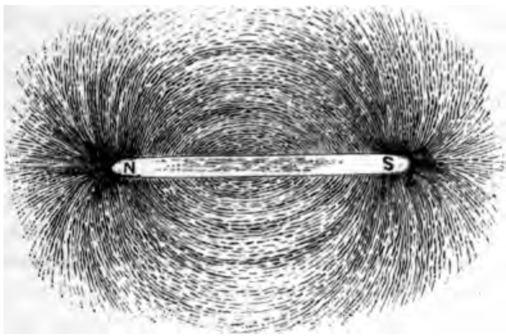


FIG. 217.—Curves of iron filings indicating the lines of force of a magnet.

often attached to a watch-guard, and move it in a circle round the large magnet. Observe and mark the position the small needle takes in different places, and notice that these lines coincide with the lines of iron filings at those places. The iron filings are, in fact, themselves short temporary magnets.

253. **Magnetic Induction.**—If a pole of a magnet is brought near a short bar of soft iron, the iron is attracted and drawn to the bar. The magnet may then be made to lift the iron bar, and on bringing another short bar near the lower end of

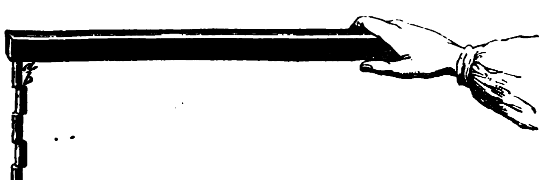


FIG. 218.—Magnetic induction.

the first *ab*, this second piece is also attracted, and may be lifted. With a strong magnet, two or three pieces more may be lifted. This experiment shows that the bar magnet first used converts the small iron bar *ab* into a magnet by its influence, its end being, of course, of opposite polarity to the pole which it touches of the large magnet.

The production of a magnet by the influence of another magnet is called magnetization by *induction*. Each of the little bars is made a magnet by induction; but they are only magnets as long as they are under the influence of the magnetized bar. When the permanent magnet is withdrawn the induced magnetism of the soft-iron bar ceases, the small bars fall apart, and retain no magnetic power. If the experiment be tried with similar small bars of steel, it will be found that only two small bars can be held by the permanent magnet that held the five bars of soft iron, but if the upper piece be now gently detached from the magnet the lower will still cling to it, and if the two pieces be separately tested by bringing them in turn to the poles of a magnetic needle, each will be found to be a magnet.

We therefore see that iron is more readily magnetized than steel, but that steel, when it is magnetized, retains its magnetic properties better than iron. Magnetic needles and other permanent magnets are always made of hard steel.

254. **Difference between Magnets and Magnetic Substances.**—A magnet is a body which possesses the property of attracting iron and steel, and of setting itself under the action of the earth in a definite direction when freely suspended. Magnetic substances are substances which are attracted by a magnet. Iron and steel are the chief magnetic substances. Nickel and cobalt are also magnetic, but in a much less degree. All the other metals are practically non-magnetic. A magnetic substance has no poles like a magnet, and all parts of it are attracted equally by either pole of a magnet. To ascertain whether a needle or a short bar of steel is a magnet or not, perform the following experiment:—

Experiment 108.—Take a mounted magnetic needle (Fig. 213), and present one end of the needle or bar to be tested in turn to the two poles of the magnetic needle. If the bar or needle has been magnetized, there will be attraction between it and one pole of the mounted needle, and repulsion between it and the other pole. If it is not a magnet there will be attraction between it and both ends of the mounted needle.

255. **Magnetic Meridian—Declination.**—A magnetic needle, when supported on a vertical pivot, or floated on water,

is found to set itself in a definite direction. In this country the direction it takes is nearly north and south, but in other parts of the world the direction is different. In all cases, however, the needle points to a certain place on the earth called the *magnetic north*, and a vertical plane passing through the needle and the magnetic north is called the *magnetic meridian*. The geographical meridian of a place is the vertical plane passing through that place and the two geographical poles, and is usually indicated on the surface of a globe by a line. The angle at any place which the direction of the needle makes with the geographical meridian, *i.e.* the angle between the magnetic meridian and the geographical meridian, is called the *magnetic declination*, or, in navigation, the Variation of the Compass (Fig. 219). As just remarked, the magnetic declination varies from place to place. At present it is about 16° 45′ W. at London, 18° 30′ W. at Plymouth, 7° W. at New York, 20° E. at Vancouver. Lines drawn on maps passing through those places on the earth's surface at which the declination is the same are called *isogonic lines* (Gk. *isos*, equal; *gonia*, an angle). There are two lines of no declination where the needle points to the true north as may be seen on the map (p. 307).

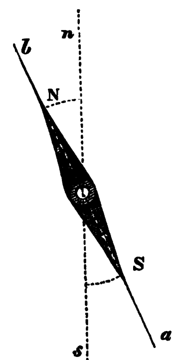


FIG. 219.—Declination of compass needle.

256. **Magnetic Inclination or Dip.**—When a steel needle has been accurately balanced at its centre of gravity, so as to remain quite horizontal before being magnetized, it is found after magnetization to lose its horizontal position, and to dip downwards with its north pole. To show this tendency, we must suspend the needle on a horizontal axis, so that it can move in the magnetic meridian in a vertical plane. An accurately balanced needle suspended on a horizontal axis is called a "dipping-needle," and when placed in the magnetic meridian, the angle which the needle makes with the horizontal is called the *magnetic inclination* or *dip*. Such a needle is shown, provided with a graduated circle

and levelling screws in Fig. 220, where the dip from the horizontal is seen to be about 70°. The angle of dip, like the angle of declination, differs in different localities. It is greatest in the polar regions, and diminishes towards the equator. Near the equator a line can be traced round the earth on all points of which there is no dip, and this line is called the *magnetic equator*. On the peninsula of Boothia Felix, in the north of Canada, there is a point where the dipping-needle stands vertical with its north pole downwards. This point is called the North Magnetic Pole. A South Magnetic Pole where a dipping-needle stands vertical with its south pole downwards exists in the southern hemisphere. Lines connecting those places on the earth's surface, at which the magnetic dip or inclination is the same, are called *isoclinic lines* (Gk. *isos*, equal; *klino*, to incline). At present the inclination at London is about 67°, and it increases as we pass northwards.

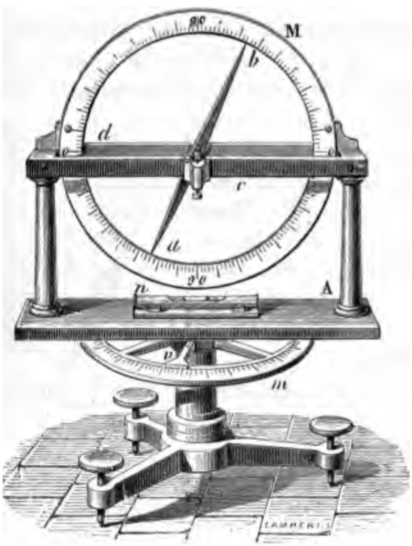


FIG. 220.—A dip-needle. (*From Ganot's "Physics."*)

257. **The Earth a Magnet.**—The behaviour of both kinds of magnetic needle may be largely accounted for by considering that the earth acts as a great magnet, or, rather, that it has a long magnetic core buried beneath its surface, and the axis of which is inclined to the earth's axis of rotation at an angle of about 20°. The action of a dipping-needle at various parts of the earth's surface will be understood on reference to Fig. 221.

(Since unlike poles attract each other, the pole beneath the

earth's surface in the north of Canada must be of opposite kind to that of the needle drawn towards it, so that there is some confusion in calling that end of the needle the north pole and that portion of the earth the earth's north magnetic pole. To avoid this in part the north pole of a magnetic needle is sometimes called the north-seeking pole, or the north magnetic pole of the earth is said to have southern polarity.)

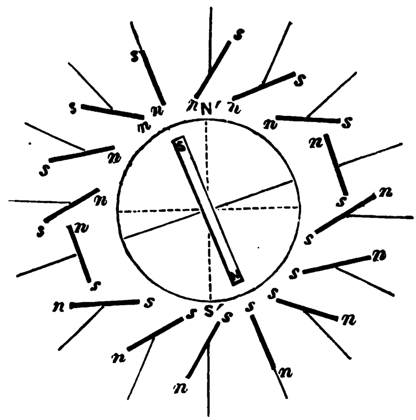


FIG. 221.

The cause of dip, and the reason of its increase as we approach certain positions on the earth, may now be further illustrated as follows :—

Experiment 109.—Place a strong bar magnet at right angles to the magnetic meridian. This is done in order to keep out the earth's magnetic action. Put the dip-needle at the centre of the magnet so that its vertical plane of motion is parallel to the axis of the magnet. Load the upper end with a little soft wax until the needle keeps horizontal. Gradually push the dip-needle towards one of the poles, and notice that a dip is produced which increases until the needle stands vertical when it is over the pole of the magnet, opposite poles being together. Bring the needle slowly back again. The dip gets less and less until it disappears when the needle is over the neutral line of the magnet, *i.e.* halfway between the poles. On moving the dip-needle towards the other pole, the opposite end of the needle dips more and more until the dip is again 90° over the pole.

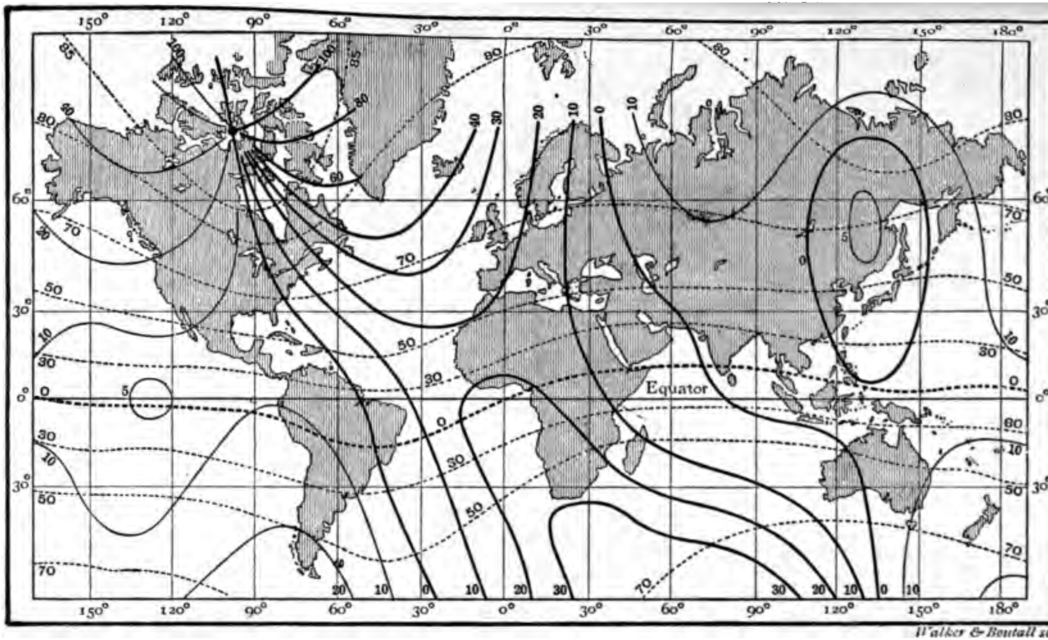
The student may make a rough dipping-needle for himself by carefully suspending a steel knitting-needle at its centre of gravity by a single thread of untwisted silk. The needle should then remain quite horizontal when suspended. Now magnetize the needle by stroking it from end to end with one pole of a bar magnet, always beginning at the same end. On again suspending the needle it will now not only set itself in the magnetic meridian, but its north pole will dip as well.

258. **Magnetic Charts.**—By means of lines drawn on the surface of a globe or on a map, charts are constructed that show the chief elements of the earth's magnetism at any period. As the inclination and declination undergo slow changes, these charts require to be brought up to date from time to time.

On a map showing *isoclinic* lines, *i.e.* lines connecting places having the same dip, we see a line of no dip called the *magnetic equator*, which is near to and roughly parallel to the geographical equator, but north of it in Asia and Africa and south of it in America. To the north of this magnetic equator there is a hemisphere in which the north pole of the needle dips, with the lines of equal dip nearly parallel to the line of no dip. To the south of the magnetic equator is an hemisphere in which the dip is south, *i.e.* where the south pole of the needle dips. There are two positions, one in the northern hemisphere and one in the southern, where the dip is 90°, so that there the magnetic force is vertical. These are called the magnetic poles of the earth or the poles of verticity, for the term "pole," when used in reference to the magnetism of the earth, must be understood to mean the places where a dipping-needle sets vertically.

A declination map or chart of *isogonic* lines shows lines connecting all places having the same magnetic declination, the amount of declination being indicated on each line. There are two chief declination lines of 0° declination, called the *agonic* lines. The first passes from Boothia Felix through Canada, the Eastern States of America, along the eastern side of the Gulf of Mexico, through the east of Brazil, and then into the South-West Atlantic; the second through Finland, Central Russia, Persia, the Indian Ocean, and Western Australia. Between these two agonic lines the declination is westerly, and outside of them it is for the most part easterly. Notice on the map how the isogonic lines come together at the north magnetic pole, and how, from the figures attached to them, it must be evident that in this neighbourhood there are places where the north pole of a magnetic needle will point to the east, places where it will point to the west, and places where it will point to the south.

It will also be noticed from the map that there is a curious



Map XII.—Magnetic Map of the Earth. The *isogonic* lines are unbroken; the *isoclinic* lines are dotted. The heavier isogonic lines pass through regions where the declination or variation is *westerly*; the lighter isogonic lines through regions of *easterly* declination.

oval patch in the north-east of Asia, along the margin of which the declination is zero, and within which it is westerly, though surrounded by a region of easterly declination.

259. **Mariner's Compass.**—An important application of the magnetic action of the earth is made in the *mariner's compass.* This is an instrument used to indicate the magnetic meridian, or the position of objects with respect to that meridian. It consists of a magnetized bar of steel attached to a circular card which turns with it, and the circumference of which is divided into thirty-two parts, called *points* or *rhumbs*. The card is so

FIG. 222.—Needle and card of mariner's compass.

fixed that the crown or fleur-de-lis is exactly over the north or marked end of the needle. The needle and card are placed in a basin, and supported at the centre on an upright sharp-pointed pivot of steel which fits into an agate cap. In this way the needle and card are capable of moving horizontally in any direction with the least possible friction. The pivot rises from the centre of a glass-covered circular box, which is suspended so that it always retains a horizontal position notwithstanding the rolling of the ship. The compass is placed in a part of a ship called the *binnacle*, in sight of the helmsman.

Inside the compass box or bowl is placed a black line called the *lubber line*, in the direction of the ship's bow, and the helmsman has to keep the point of the card which marks out the ship's course in contact with this line.

In a land compass the magnetic needle is so arranged that it moves in a case above a *fixed* graduated card. Knowing the declination of the compass at any place, the traveller can determine the geographical meridian, or north and south line, by turning the compass until the needle deviates from the line NS by a quantity equal to the declination.

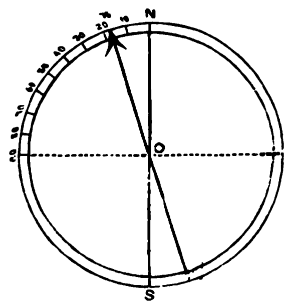


FIG. 223.—Diagram of land compass.

The notation of the compass is as follows:—

The circumference being divided into the four quadrants by two diameters at right angles, the extremities of these diameters are the four cardinal points (*cardo*, a hinge), marked N., S., E., W. (north, south, east, west). Bisecting each of the quadrants, the several points of bisection are denoted by placing the two letters at the extremities of the quadrant in juxtaposition. Thus N.E. (north-east) denotes the point which is half-way between north and east; and so with N.W., S.E., S.W. (north-west, south-east, south-west). Let the octants so formed next be bisected; the points of division are denoted by prefixing to each of the above combinations, first the one, and then the other, of the two cardinal points of which it is formed. Thus N.E. gives N.N.E. and E.N.E. (north-north-east and east-north-east); and so in respect of the other. Sixteen points have thus been named. Let the distance be again bisected, then each of the points so found is expressed by that one of the preceding

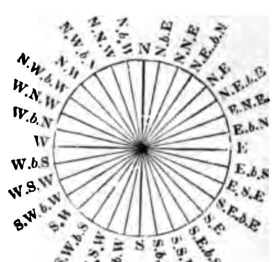


FIG. 224.—Points of compass.

points already named to which it is nearest, followed by the name of the cardinal point towards which its departure from the nearest points leads it, the two being separated by the letter *b* (by). Thus the point halfway between N. and N.N.E. is N. by E. (north by east); that which is halfway between N.N.E. and N.E. is N.E. by N. (north-east by north); etc. The whole of the thirty-two points are thus distinguished, as in Fig. 224.

260. **Finding the True North and South Line by the Compass.**—The variation of the compass, or the declination of the magnetic needle from the true north and south line, varies in the British Isles from about $16\frac{1}{2}°$ W. at the south-east of England to 24° W. at the west of Ireland. There is annually a decrease of this western declination of about 7′. At present, the amount of declination is as follows at certain stations: Dover, 16° 30′; Yarmouth, 16° 45′; London, 17° 12′; Hull, 18° 30′; about 19° at Gloucester, Birmingham, York, and Whitby; about 20° at Swansea and Liverpool; about 21° at Holyhead and Glasgow; Dublin, 21° 30′; Cork, 22°. To find the true north-and-south line, *i.e.* the geographical meridian, by means of a magnetic needle, we must draw a line with the help of a graduated circle through the point of suspension of the needle, the requisite number of degrees (according to the declination of the place of observation) to the *east* or right of the line marked out by the magnetic needle when at rest; or the needle must be so placed that it points the declination number of degrees west of the north point of the compass card, when the line joining the north and south points of the card or dial will be the true north-and-south line.

CHAPTER XXII.

THE SHAPE AND MOVEMENTS OF THE EARTH.

261. **Introductory Remarks.**—On looking around us we soon learn that the sun rises every day above the eastern part of the horizon, reaches his highest position in the south at noon, and then declines, to set in the west. Continuing our observations for some time, we may notice that, though the sun is always exactly in the south at noon, he does not rise nor set at one and the same place nor at the same time throughout the year. At night the moon and the stars attract our attention. In the open country we appear to be situated at the centre of an immense hollow globe or sphere, on the inner or concave surface of which the stars and other heavenly bodies appear to lie. With careful watching we may notice some of the stars rise above the eastern part of the horizon, ascend to their highest point in the south, and then descend to disappear below the western horizon. The same stars rise and set exactly at the same points, though not exactly at the same time, day after day throughout the year. Some stars, however, never set, but turn every day in a complete circle above the horizon, round a fixed point of the heavens. If we look towards the north in our latitude, we may at certain times see the stars arranged on that part of the celestial vault in the mode shown in Fig. 225, though if the night be very clear and without moon more stars may be seen than are indicated. A careful watch of these stars, continued for some time, will convince us that they are revolving in a direction contrary to the hands of a watch, around a point very near the central star of the figure. This star, around which the others appear to *revolve in parallel* circles, and which has the same distance

above the horizon as the observer's latitude, is know as *Polaris*, or the *Pole Star*. Stars that revolve round it without setting are called *circumpolar stars*. The seven stars seen on the right of the figure are such stars, and form part of a group known as the Great Bear. Two of the stars in this group are known as the "pointers," because they indicate the direction in which we

FIG. 225.—The starry sphere, looking north. (Great Bear on the right.)

may look for the Pole Star, whether the group is in the position shown in the figure or in any other part of its diurnal circle; for the stars of the Great Bear, always keeping the same position with respect to each other, are among the number of stars which in our latitude are always above the horizon, and, though only visible to the naked eye after the sun's powerful light is withdrawn, they may be seen with a telescope in all

parts of their course. We shall return to the diurnal movements of the stars several times.

If we wish to point out the *position* of a star on the sphere of the heavens, or the apparent distance of two stars from one another, it is clear that we cannot do this by using our measure of *length*. We cannot say that a star is so many yards or miles from the horizon, or that two stars are so many inches apart. To indicate apparent distance in the sky, we must express the distance in *degrees*, or, in other words, use *angular measure*. Before we explain this we will remind the reader of the meaning of a few common terms.

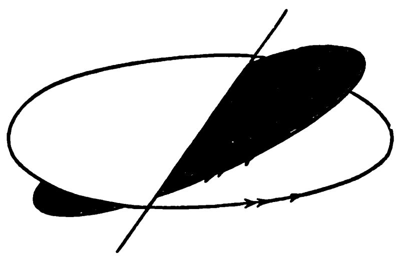


FIG. 226.—Two intersecting planes.

A *plane*, or plane surface, is a surface on which a straight edge can lie evenly in all directions. It is regarded as having length and breadth, but no thickness. A good floor, the sloping surface of a desk, and the face of a blackboard are all plane surfaces. The position of objects is often described by giving their perpendicular distance from a plane. The intersection of two planes is a straight line.

A *circle* is a plane figure bounded by one line, which is called the circumference, and is such that all straight lines drawn from its centre (radii) to the circumference are equal.

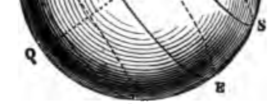


FIG. 227.—Globe, with great and small circles.

A *sphere*, or globe, is a round body bounded by a curved surface, every point of which surface is equally distant from the centre. If a section be made by a plane passing through the centre of a sphere, this plane cuts the surface of the sphere in a *great circle*. Any number of great circles may be supposed to be drawn upon a sphere, *and all great circles bisect one another.* Any section of a

sphere made by a plane which does not pass through the centre cuts the surface of a sphere in what is called a ***small circle.*** Fig. 227 represents a sphere with a great circle EE (seen obliquely as an ellipse) made by a plane passing through the centre C; RR, SS, and TT are small circles.

The earth on which we live is a globe, as will shortly be proved, and is often called the ***terrestrial sphere.*** The ***celestial sphere*** is that sphere on which all the heavenly bodies, as the

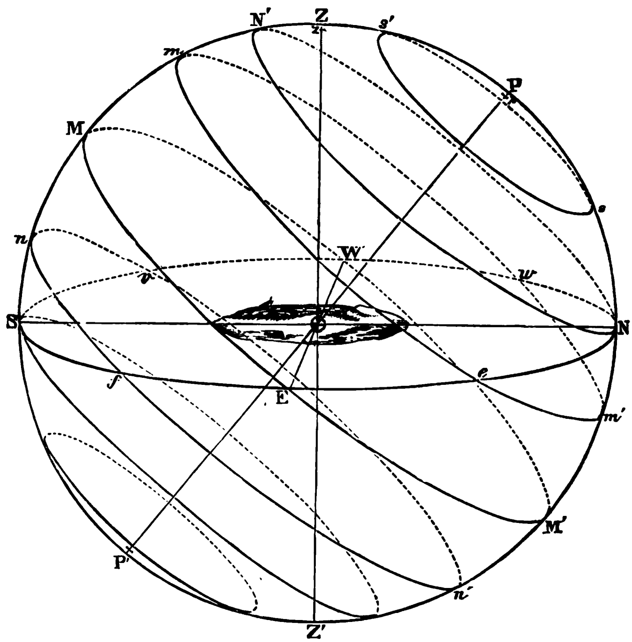


FIG. 228.—The celestial sphere at the latitude of London.

sun and stars, appear to be situated. In order to define the position of the heavenly bodies on the inner surface of the celestial sphere, we imagine certain circles traced on its surface, the observer being regarded as situated at its centre. In Fig. 228, let the letter O represent the earth, though in reality our earth is but a mere point, so small is it in comparison with the immensity of the celestial sphere. The diameter of the earth

about which it turns is called its axis, and when this is produced both ways it meets the celestial sphere in the points P and P′: P is the north pole of the heavens, and P′ is the south pole of the heavens, and the celestial sphere seems, in consequence of the earth's rotation, to turn daily round the axis PP′.

An observer on a level part of the earth sees around him a circular plane bounding his view called the plane of the *visible horizon.* A great circle of the heavens formed by a plane passing through the centre of the earth, and parallel to the plane of the visible horizon, is called the *rational horizon.* At the infinite distance of the heavens these two planes meet and divide the celestial sphere into a visible hemisphere and an invisible hemisphere. The rational horizon is indicated by the great circle ESWN. The central point Z of the visible hemisphere directly over our heads is called the *zenith*, and the central point of the invisible half Z′ is called the *nadir.* The great circle MEM′W, formed by a plane passing through the centre and perpendicular to the axis, is called the *celestial equator.* It is the plane of the earth's equator extended to meet the heavens, and it intersects the horizon at E and W, the east and west points. The small circles parallel to the equator represent the diurnal paths of the stars. A star rising at E midway between the north and south points ascends in about six hours to its highest point or culmination M on the meridian SZPN, passes thence in the same time to W, where it sets, to rise again at E on the next day. If a star rises at *f*, its diurnal course above the horizon is smaller, and the time during which it is visible is shorter. It transits the meridian or culminates at *n*. Stars rising anywhere above the horizon on the arc EN culminate somewhere on the meridian between M and N′, remain above the horizon more than twelve hours, and set just as far to the north of the west point as they rose north of the east point. Other stars, whose distances from the pole star are less than the observer's latitude, are circumpolar stars, and perform the whole of their diurnal circles as NN′ and *ss′* above the horizon.

The stars whose daily motions we have just been describing are called *fixed stars*, because they keep the same relative

position day after day and year after year. Other heavenly bodies that appear like stars to the naked eye, besides rising and setting, move among the fixed stars with a slow erratic motion, and are hence called *planets* (Gr. *planetes*, a wanderer).

262. **The Use of Angular Measurement in Astronomy.**—*Altitude and Azimuth.*—Angular measurement is a very convenient method of indicating the position of the heavenly bodies. The position of a star may be fixed, for example, by referring it to certain imaginary great circles of the heavens, and we may measure its position by arcs perpendicular to such great circles.

(*a*) *First Method of defining the Position of a Heavenly Body.*—In this method the objects are referred to the horizon as the fundamental plane, and in the northern hemisphere the south point of the horizon is the point of origin. Let us draw a diagram to represent the visible portion of the celestial sphere. We can do this by describing a semicircle to represent the observer's meridian. A great circle (seen obliquely as an ellipse) joining the ends of this semicircle will represent the horizon. A point vertically over the observer's head will represent the *zenith.* A point measured off from the north point of the horizon by a distance equal to the latitude of the spectator will mark the position of the north pole of the heavens (Fig. 229).

Vertical circles are great circles which pass through the zenith and nadir, and are perpendicular to the horizon.

Parallels of altitude are small circles parallel to the horizon.

The *prime vertical* is the vertical circle that passes through the east and west points of the horizon.

The *celestial meridian* is the great circle passing through the zenith and the poles of the celestial sphere. Its intersection with the horizon marks the north and south points of the horizon, and its plane is perpendicular to the plane of the prime vertical.

The *altitude* of a heavenly body is its elevation above the horizon measured on the arc of the vertical circle passing through the body. It may also be measured by the angle which this arc subtends at the centre of the horizon. (See Fig. 229.)

The *zenith distance* of a body is its angular distance from the zenith, and is therefore the complement of the altitude. Altitude + zenith distance = 90°.

As a star approaches the meridian its zenith distance diminishes, and a star attains its greatest altitude on the meridian, when it is said to *culminate.* When a star has reached the meridian one half of its visible path is accomplished, and the passage of a heavenly body over the meridian is called its *transit.* A circumpolar star—*i.e.* one whose whole diurnal circle is above the horizon—has an upper and a lower culmination, and the half sum of these two altitudes gives the latitude of the place.

The *azimuth* of a body is the arc of the horizon intercepted between the south point of the horizon and the foot of the vertical circle passing through the body. It is measured by

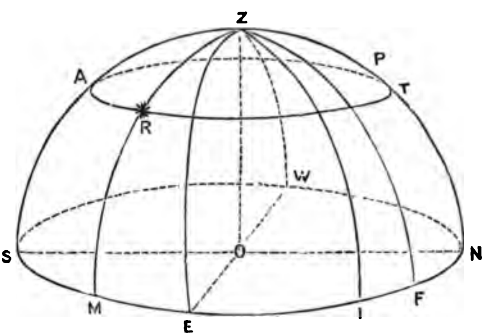


FIG. 229.—The horizon and vertical circles.

), the observer's position.
Z, the zenith. P, the pole.
SENW, the horizon.
SZPN, the meridian.
EZW, the prime vertical.
MZ, IZ, FZ, arcs of other vertical circles.
R, a star's position.

ART, a parallel of altitude.
ZRM, arc of star's vertical circle.
Arc SM, or angle SZM, star's azimuth.
Arc MR, or angle subtended by it at O, star's altitude.
Arc RZ, star's zenith distance.

he number of degrees in the arc of the horizon intercepted etween the south point and the foot of the vertical circle assing through the object. In the figure the star R has an ltitude of about 55° and an azimuth 45° E. of south. (Sometimes azimuth is reckoned from the south through the west. n this case the azimuth of R would be 315°.) Other stars

may be marked on the figure, and their altitude as well as their azimuth or "bearing" estimated. Stars have the same altitude if on the same parallel of altitude, and the same azimuth if on the same vertical circle. Thus all stars on the parallel of altitude ART are at the same height above the horizon, and all stars on the vertical arc ZM have the same azimuth. A star on the vertical arc ZW two-thirds above the horizon would have an altitude of 60° and an azimuth of 270° measured eastward from the south.

The *amplitude* of a heavenly body is the angular distance of its rising point from the east and of its setting point from the west, measured along the horizon, or measured by the angle which this arc subtends at the observer's position in the centre of the horizon. The amplitude of the fixed stars remains the same throughout the year, but the sun's amplitude varies during the year. It is nothing at the equinoxes, and about 40° at the solstices for our latitude. Most of the foregoing definitions are illustrated by the figure.

Altitude and azimuth are not often the most suitable ways of indicating the position of a heavenly body, for two reasons: first, because the horizon changes as we change our position on the earth's surface, or, in other words, the "sphere of observation" varies with change of place; secondly, the position of a star or other heavenly body with reference to the horizon is continually changing at the same place owing to the apparent rotation of the celestial sphere around the horizon. In reality it is the daily rotation of the earth on its axis which causes the horizon to revolve and uncover the fixed stars and the imaginary circles of the celestial sphere, though it is often more simple and convenient to describe the phenomena as if the celestial sphere were rotating and the horizon at rest.

(*b*) *Second Method of defining the Position of a Heavenly Body.—Declination and Right Ascension.*—By referring the places of the heavenly bodies to the celestial equator as the fundamental plane instead of the horizon, we obtain elements independent of the observer's position, and, as far as the fixed stars are concerned, independent of the time (except a very small change to be explained hereafter).

The *celestial poles* are the points where the earth's axis of ıtion, prolonged indefinitely, would meet the celestial sphere. y line from a point on the earth at any part of its orbit, *'allel to this axis*, vanishes at the same points at the infinite tance of this sphere. The *celestial equator* or *equinoctial* is : great circle of the celestial sphere 90° from each celestial le. It may also be regarded as the great circle in which the ıne of the earth's equator cuts the celestial sphere. At its

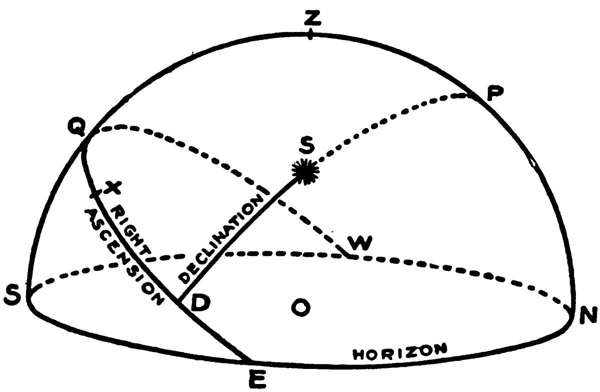


FIG. 230.

EQW, equator.
SZPN, meridian.
SENW, horizon.

Arc SD, declination.
Arc XD, right ascension.
Arc SP, north polar distance.

hest point it is just as far below the zenith as the pole is ›ve the horizon, and it cuts the horizon at the east and west nts.

The *declination* of a heavenly body is its distance from the ıator measured on the arc of a great circle passing through body and the pole. It is reckoned positive (+) north of equator, and negative (−) south of it.

The *polar distance* of a star is the angular distance of the : from the pole measured on the arc of a great circle passing n the pole through the star. Declination + polar disce = 90°.

The *right ascension* of a star is the arc of the equator ercepted between the point where a perpendicular from the : meets the equator and the point called the first point of

Aries. In other words, *right ascension* is the angular distance from the first point of Aries. The first point of Aries may here be regarded as the fixed point on the equator where the sun's path, called the *ecliptic*, meets the equator in spring. The opposite point is called the first point of Libra.

The declination and right ascension of a star, unlike the altitude and azimuth, remain the same during the daily rotation of the heavens. Right ascension is always measured eastward all round the equator from 0° to 360°. Fig. 230 shows how to indicate the declination and right ascension of a star. The point Q is found by measuring 90° from P, and the half of the celestial equator above the horizon meets the horizon at the east and west points. A point, X, is taken to indicate the first point of Aries. The number of degrees in the arc SD perpendicular to the equator measures the *declination* of the star S, and the arc XD measures the *right ascension* of the star. If the reader will draw a quadrant from Z through S, it will meet the horizon perpendicularly, and he will be able to see the altitude and azimuth of the star.

The two systems of great circles, with the co-ordinates by which the position of the heavenly bodies are defined, may be thus briefly summarized :—

With regard to the horizon, or the plane perpendicular to the plumb-line—

Altitude = distance from the plane of the horizon.

Azimuth = distance from the south point of the horizon.

With regard to the plane of the equator or plane of earth's rotation—

Declination = distance north or south of the equatorial plane.

Right Ascension = distance from the first point of Aries.

In both these cases distance means angular distance, or distance measured in degrees on the arc of a great circle.

263. **Measurement of Time.**—Round the equator of the earth, which is a circle, there are 360 degrees. We shall find later on that the earth rotates so that the sun reaches its highest point in the heavens once every day for each place on the earth's surface. When the sun is at this highest point it is noon, and the period of time from one noon to the next noon is called

a "solar day." Now, the length of time from noon to noon is not always the same, varying a little at different parts of the year. But we can take the average of these different days, and we call that average the *mean solar day.* It is used as the unit in all ordinary civil reckoning.

We divide the day into 24 hours, and each hour into 60 minutes, and each minute into 60 seconds. Now, the earth turns round completely, *i.e.* through 360 degrees, in 24 hours, or through 1 degree in 4 minutes.

Of course, we do not actually measure the flight of time by the rotation of the earth, though we see how our unit of time, viz. the day, comes to depend on this rotation. We measure it by means of a clock, the pointers of which indicate the hours of the day, and which is so regulated that an hour marked by it is a twenty-fourth part of the mean solar day.

A clock consists of a means for counting the number of swings or oscillations of a pendulum, and an arrangement for keeping up those oscillations. It serves as a means of measuring a mean solar day and its divisions.

264. **The Sundial.**—There is another method of measuring time sometimes used—that by means of a sundial. The use of

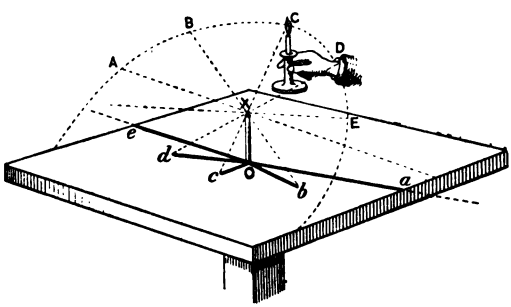


FIG. 231.—Shadow cast by a vertical rod when a candle is moved round it in a semicircle.

the sundial may be illustrated by a simple experiment. Fasten a small rod, OX, at right angles to a flat board (Fig. 231). With the board flat on the table, move a candle in a semicircle above the table, and note the change in the length of the shadow and in the angle that the shadow makes. With the candle at its

highest point, C, the shadow OC is the shortest. Mark the line O*c*. As the candle moves to D and E, the shadows O*d*, O*e* lengthen, and the angle made with O*c* increases.

The essential part of a sundial is a rod or the edge of a piece of metal called a *style*, which is placed parallel to the earth's axis, and casts a shadow on the plate called the *dial*. The plate is marked out with the different hours of the day, and the shadow of the style cast by the sun passing over it, as the sun moves through the sky, indicates the time of day. As the sun rises in the east, the shadow falls to the west; as the motion progresses, the sun moves to the south, and the shadow to the north[1] till at noon it is due north, and on the mark indicating XII. In the afternoon the shadow passes eastward. The figure (Fig. 233) shows the usual form of a horizontal sundial. This indication of time, depending on the motion of the sun, will not necessarily agree with the indication by a clock; for we have pointed out that the true solar day, or length of time from noon to noon by

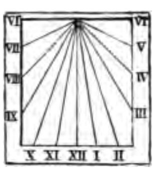


FIG. 232.—Vertical sundial, facing south.

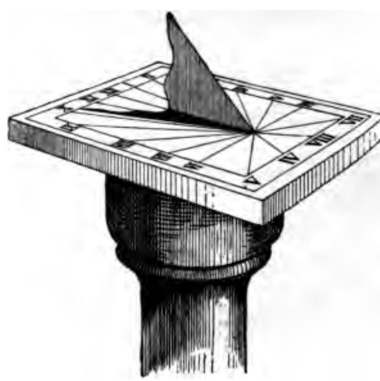


FIG. 233.—Horizontal sundial, with shadow of style indicating 10.15 a.m.

the sun, is not of constant length at all periods of the year. In fact, the sundial indicates "true solar time," the clock indicates "mean solar time." As just stated, the *style* or *gnomon*, which is usually a rod or edge of a thin plate of metal, must be *parallel*

[1] In the Southern Hemisphere, "south" and "north" must here be interchanged.

to the earth's axis. It must, therefore, point to the celestial pole, and make an angle with the horizontal dial-plate equal to the latitude of the place. At London this angle will be $51\frac{1}{2}°$; at Edinburgh, 56°; and thus a dial serviceable at one latitude will be of no use at a different latitude. Since the daily apparent motion of the sun due to the earth's rotation appears to carry it round the earth's axis in 24 hours, the sun also appears to travel round the style of the dial, and it thus casts the shadow of the style upon the side of the dial away from the sun. At noon, when the sun is on the meridian of the place of observation, the shadow will be cast exactly north. As the sun appears to move through 15 degrees each hour, the position of other hour-lines on the dial-plate may be found by marking the position of the shadow at the end of each movement of the sun through 15 degrees. The graduations that mark the hours on a dial-plate are not at equal intervals, as the horizontal plane of a plate is not perpendicular to the earth's axis, except at the poles.

265. **Size and Shape of the Earth.**—Before discussing the movements of the earth, it will be well to consider the *size and shape of the earth.* The earth is a sphere, or very nearly so.

FIG. 234.

That it is not flat is shown by watching a ship on the surface of the sea, which, in sailing away from the land, disappears as it were behind a hill of water, first the hull sinking out of sight,

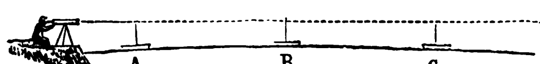


FIG. 235.—Showing how the roundness of the earth can be proved by means of three boats on a large sheet of water.

then the sails, and lastly the very tops of the masts. A further proof that it is not flat is shown by arranging three posts along a level piece of water. The three posts A, B, C, are of the same height above the surface of the water. On looking with a

telescope so as to see the tops of the posts A and C, the top of the post B will be above the line of sight.

The rise of what we call a great plain, like the level sea, between two observers, or the depression of the surface of the sea from any point, is 8 inches in one mile, 8×2^2 in two miles, 8×3^2 in three miles, and so on for a great distance; *i.e.* the depression is equal to 8 inches multiplied by the square of the number of miles. This can only be true on a globe of a certain size.

That the earth is a sphere is proved by the fact that the horizon, which includes the whole of the earth visible at any one spot, is always a circle, wherever the observer may be, and this circle grows larger the higher from the ground the observer may be. A sphere is the only surface which has this property. [This horizon seen from some points may be broken by mountains, and hence not be a circle, but at all spots surrounded by level ground, or by the sea, it is a circle.]

If the earth were a plane the sun would rise and would reach its meridian altitude at the same time at all places east and west of Greenwich, that is, *local time would everywhere be the same.* But we can soon learn by electric telegraph that this is not the case. When it is noon at London it will be found on inquiry that it is 1 p.m. at a place 15 degrees east of London, and that it is 7 a.m. at Philadelphia, 75 degrees west of London. The earth, therefore, must be round east and west. The changing altitude of the stars as we travel north or south proves that it must be round in this direction also.

Furthermore, the shadow of the earth cast by the sun on the moon in an eclipse is always round; and again a sphere is the only body which has such a property.

The fact that the earth has often been circumnavigated in various directions also proves that the earth is round, and proves also that the earth is of limited size.

As before remarked, however, it is not quite a perfect sphere, but an ellipsoid or *oblate spheroid*, being somewhat flattened about the poles and having a bulging about the equator (see Fig. 21). This is *proved* by finding that the length of a degree on a meridian circle of the earth near the pole is a little longer

than the length of a degree on the same meridian near the equator. It must therefore be part of a greater circle than the degree near the equator, for the larger the circle the longer is the $\frac{1}{360}$ part of it and the flatter is its curve. Further, the increase of the force of gravitation near the poles beyond that due to the decrease of centrifugal force there (par. 17) shows that the earth is slightly flattened at the poles.

Fig. 236 illustrates the shape of the earth, and shows that the earth's surface is less curved near the poles than at the equator. AB subtends the same number of degrees as *ab*, but it is plainly an arc of a larger circle whose centre is at a greater distance. The length of AB is therefore greater than the length of *ab*.

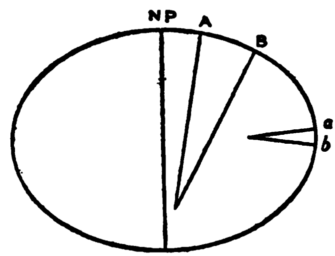


FIG. 236.—Showing that the earth is flattened at the poles.

A degree of latitude near the poles is about 69·4 miles, and a degree near the equator is about 68·7 miles, so that an observer must pass over these distances south or north at these positions to produce a difference of one degree in the altitude of the pole star. If the earth were a true sphere, the length of a degree in all latitudes would be the same. Degrees of *longitude*, being measured between the meridians, are longest at the equator, and diminish rapidly as the meridians approach towards the poles.

Having found by measurement the actual length of a degree on the earth to be about 69 miles, we find the earth's circumference to be $69 \times 360 = 24{,}840$ miles. Dividing this result by $3\frac{1}{7}$, we find the diameter to be about 8000 miles. More exactly, the polar diameter is 7899·6 miles, and the equatorial diameter 7926·6 miles—a difference of 27 miles.

266. **Terrestrial Latitude and Longitude.**—To indicate the position of any one spot of the earth, we imagine circles drawn over it, and draw corresponding circles on a globe which represents the earth. The *axis* of the earth is the imaginary line about which we shall find that the earth seems to rotate. The points

where this axis cuts the surface are called the *north* and *south poles.* All places equally distant from the two poles are on a great circle called the *equator.* Smaller circles drawn on the globe parallel to the equator are called *parallels of latitude;* and these are drawn on both sides of the equator, being smaller the nearer they are to the poles. They are drawn at equal intervals, and, as on the quadrant of a circle from the equator to the pole there are 90 degrees, these circles are marked off in degrees, the equator being 0°, the next circle being called 10° north latitude, or south latitude, as the case may be, the next 20°, and so on; the last circle being really a point of the pole itself, 90 degrees from the equator. Of course, we might have more circles than are here indicated, as the intervals might be 1 degree or 5 degrees instead of 10 degrees. All places on the same parallel circle have the same latitude.

Other circles are drawn, all of the same size, and all passing through both poles, cutting the equator and all parallels of latitude at right angles. The intervals between these circles are equal at the equator, and are also equal when they cut the parallels of latitude, but the intervals in the latter case are smaller than in the former, as the equatorial circle is larger than any of the other circles of latitude. These new circles are called circles of *longitude*, or *meridians* (L. *meridies*, midday), because when any of these lines is opposite to the sun, it is midday or twelve o'clock at all places situated on that meridian on the same side of the globe, and midnight on the opposite side. They are indicated by degrees; and as there are 360 degrees round the equator, we start from one of the circles of longitude and reckon 180 degrees each way, that is, eastward and westward, till we come to the point opposite to that from which we started.

In England we reckon as the first meridian, or 0°, the circle of longitude which passes through Greenwich, and count the longitude eastward and westward from the starting-point. In other countries other first meridians are sometimes taken, though there is now an almost general agreement to adopt that of Greenwich. If, then, we are given the latitude and longitude of a place on the earth, we can easily indicate its position on a sphere.

The degrees of latitude as seen on many maps are drawn at equal intervals, though this is not absolutely correct, owing to the slight flattening at the poles. Hence a degree of latitude may be taken as equal to about 69 miles; for 24,858 miles (the mean circumference) divided by 360 is equal to 69 nearly. The lines of longitude, however, vary in their distance from one another, approaching towards the poles where they meet in a point. Hence a degree of longitude is about 69 miles at the

FIG. 237.—Lines of latitude and longitude.

equator only, its length becoming less and less as we get nearer the poles. Thus at London, $51\frac{1}{2}^\circ$ N. lat., a degree of longitude is only equal to about 42 miles.

We shall presently prove that the phenomena of day and night are the result of the rotation of the earth on its axis. It will thus be plain that places not in the same longitude will not have their noon at the same time. The earth turns completely round, *i.e.* through 360 degrees, in 24 hours, and therefore through 15 degrees in 1 hour, or through 1 degree in 4 minutes. Hence a place 10 degrees east of Greenwich has its

noon 40 minutes before Greenwich, while at a place 10 degrees west of Greenwich it is 11.20 a.m. when it is noon at Greenwich. The pupil will thus see how to find the time of the day at any place in the world, "local time" as it is called, corresponding to any particular time at another place, having given the longitude of the two places. It is also worthy of note, that as the mean circumference of the earth is 24,858 miles, and as it rotates on its axis once in every 24 hours, every place on the equator must be carried round at a rate of more than a thousand miles an hour. As we remove from the equator the circles of latitude become smaller, and their rate of motion proportionally less. Thus at the 60th parallel the rate is only five hundred miles an hour, while at the poles the motion ceases altogether.

267. **The Zones of the Earth.**—Certain parallels of latitude divide the earth's surface into five natural divisions termed *zones*. As will shortly be explained, the position of these dividing parallels of latitude is fixed by the apparent yearly movements of the sun north and south of the celestial equator along the ecliptic. The part of the earth between the parallels of $23\frac{1}{2}°$ north and south of the equator (more exactly $23° 27'$) is called the Torrid Zone, and the bounding parallels are the Tropic of Cancer on the north side, and the Tropic of Capricorn on the south side. The parallel of $66\frac{1}{2}°$ north latitude is called the Arctic Circle. The belt of land round the earth between the Tropic of Cancer and the Arctic Circle is called the North Temperate Zone. The parallel of $66\frac{1}{2}°$ south latitude is called the Antarctic Circle, and the belt of land between it and the Tropic of

FIG. 238.—Illustrating the zones into which the earth is divided.

Capricorn is the South Temperate Zone. The regions round the two poles bounded by the Arctic and Antarctic Circles respectively are called the Frigid Zones.

268. **How a Day is lost or gained in going round the World.**—Travelling westwards, or towards sunset, causes the sun to set later and to rise later, and the day, as measured from one meridian passage of the sun to another, is more than 24 hours long. The local time of the places reached continually gets slower, and the traveller moves the hands of his watch back 1 hour for every 15 degrees of longitude westward. If he were to start from Greenwich and proceed westwards round the earth, in a certain number of rotations of the earth he would see one less than this number of noons, and record one day less; *i.e.* he would have made $n-1$ turns with respect to the sun, while the observer who remained behind had made n turns. Hence on reaching the place from which he started, he appears to have "lost a day," being one day of the month behind, though it is really made up of the hours that he puts his watch back. Similarly, a traveller going round the world eastward finds the local time continually getting faster, puts his watch forward, and seems on his return to have "gained a day." In order to keep the dates right, therefore, mariners going westward add on a day when crossing the meridian 180° from Greenwich, and drop a day when crossing the same meridian going eastward.

269. **How to find the Meridian of any Place, and the Cardinal Points.**—The meridian of any place is the line passing from the north pole to the south pole through that place, or it may be described as the line joining the north and south points of the horizon. This line may be found in several ways. By setting up a vertical rod on a plane surface and finding the direction of the shadow at noon when it is shortest, we shall obtain the direction of the meridian or north-and-south line. It is so difficult to settle when the shadow is shortest, that it is best to draw one or more circles round the rod

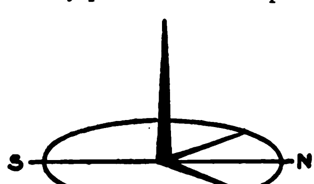


FIG. 239.—Method of finding the meridian.

and note the direction of the shadow when the point just reaches a circle before noon, and when it just reaches the same circle after noon. The line bisecting the angle between these two shadows is the meridian line. We might also find the meridian line by drawing a line from a fixed point to the rising sun, and from the same point to the setting sun. The line bisecting this angle would also run north and south. A line at right angles to the meridian would run due east and west, and thus the cardinal points would be determined. We may also fix the meridian by means of the stars. A telescope pointing to any star when at its greatest altitude above the horizon or at the moment of transit, would be pointing along the meridian.[1] A telescope pointing to the pole star, or more accurately the point about which it appears to turn, would be pointing in the plane of the meridian, and the north point of the horizon is vertically beneath the pole in north latitude. We can also find the geographical meridian by means of a mariner's compass if we know the declination or variation of the needle at the place of observation (see par. 260).

270. **Apparent Daily Rotation of the Heavenly Bodies.**—Our earth is a globe situated in celestial space and surrounded by other globes at various distances from it. We have already mentioned how the celestial sphere seems to rotate each day, causing the sun, moon, and some of the stars to rise and set. Thus the sun rises daily above the eastern part of the horizon, ascends slowly to its highest elevation, and then slowly descends along the same arc to sink in the west. When at its highest point it is noon, and the centre of the sun is exactly over the meridian of the place of observation. We say, therefore, that the sun crosses or *transits* the meridian when at its greatest altitude each day. It is evident that different places on the earth's surface may be on the same meridian and have their noon at the same time, but it can never be noon on two meridians at the same time. The time between two successive passages of the sun across a meridian is called a *solar day*, and

[1] A more accurate result will be obtained if a star be observed by means of a suitable telescope when it is at the same altitude east and west of the meridian, for the mean of the two readings of the azimuth circle will give the exact direction of the meridian.

is equal to about 24 hours of clock time. We say "about" 24 hours of clock time, because, as will shortly be shown, the true solar day, or actual interval of time between two meridian passages of the sun, is not of the same length at all parts of the year, and it is the average of the different solar days in a year, or "the mean solar day," which is exactly 24 hours of clock

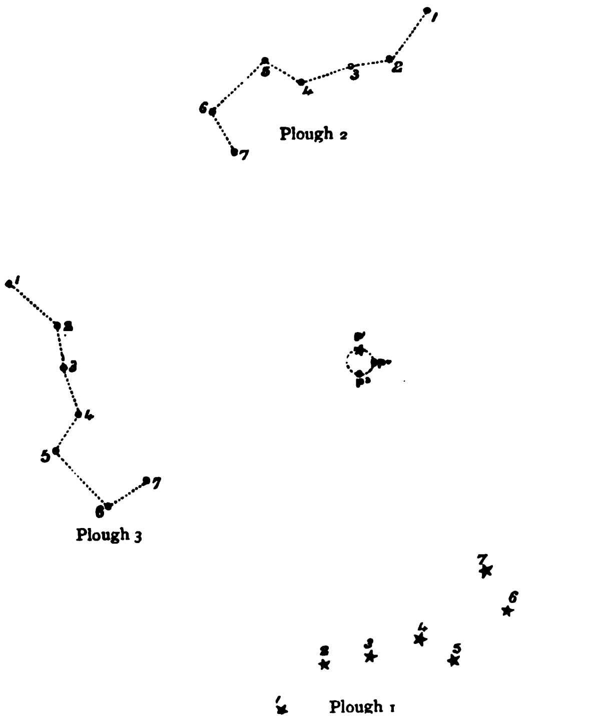


FIG. 240.—Three positions of the Plough (Great Bear) and the Pole Star in their daily revolution round the pole.

time. The diurnal paths of the stars have been already referred to (see par. 261). Looking towards the pole star, which can always be found on a clear night by the pointers of the Great Bear, or Plough, as its seven stars are also called, we find the stars describing daily circles of various sizes round the pole of the heavens, and a first examination may therefore lead us to

suppose that the various celestial bodies external to the earth perform a daily revolution from east to west around a line or axis terminating at the pole star, all completing their revolution in the same time. But this is really not the case, for there is a more satisfactory explanation. The earth, in fact, rotates daily on an axis, carrying with it the atmosphere and clouds, which are indeed a part of it.

The Pole Star, in fact, describes a small circle round the true celestial pole every 24 hours. The diurnal paths of other stars are also circular round the celestial pole, the size of the circle increasing with distance from the pole. On exposing a *photographic plate* during the night with the lens of the camera directed north and upward to the pole, a series of concentric arcs of circles will be traced on the plate the length of the arcs depending on the distance of the stars from the pole, and on the time of exposure. Thus six-hour trails on the plate would give one-fourth of the diurnal circle of a star, provided no clouds intervened.

271. **Rotation of the Earth on its Axis.**—Let us consider what happens when we are in motion in a railway train, or on a steamboat. If we look out of the window, the trees, telegraph poles, and all bodies external to the train, which we know to be stationary, appear to be in rapid motion in a direction contrary to our motion. The deception is greater if the train or steamboat moves very smoothly, without any jerks or jolting. Indeed, with a very smooth motion we might think that we are stationary, and all outside objects are moving rapidly past us; but on closer investigation we should really find that outside objects were stationary, while we were moving rapidly in an opposite direction to that in which we thought the objects were moving.

Now let us apply this, on a larger scale, to the whole earth and bodies external to it. The daily motions of sun, moon, and stars are explainable by supposing that we and the earth on which we stand are stationary, while those bodies move uniformly round us. But these apparent motions are equally explainable by supposing that these bodies are fixed in different positions round the earth, and the earth rotates round in a direction opposite to that in which they seem to move, *i.e.* the earth must turn from west to east, for they seem to move from east to west. This rotation of the earth would account for the rising in succession of the sun, moon, and the different

stars, which follow one another to the west, and disappear, only to reappear in the same manner on the succeeding day. Everything on the earth moves with it, and moves smoothly, and thus the motion is not evident to our senses. Are we, then, to suppose that these heavenly bodies move round the earth, or that the earth rotating itself gives them an apparent motion? We have very good reasons for supposing that it is the earth which rotates, and thus gives us the daily rising and setting of these external bodies. The reasons are—

(1) All of these bodies are very distant from the earth, the stars especially being very far distant, so that they would have to move at an immensely rapid pace to get round the earth in one day, as they seem to do; while on the contrary, it would be at a comparatively slow pace that the earth would have to move round on its own axis so as to make one complete turn in the single day. The external bodies are then considered to be stationary. It seems more reasonable that the earth turns thus slowly than that they move at such an immense pace.

(2) All these external bodies appear to move round us in exactly the same time—one day, or 24 hours. If we consider how they are scattered over all the different parts of the heavens, and at different distances from the earth, we should not expect all to move round us in the same time, unless indeed they were connected by some means, such as rods and bars, with one another. We see no signs of any such connections, however, between these different bodies. If we suppose that the earth rotates whilst they are stationary, then at once we see that they will appear to move in a direction opposite to that in which the earth rotates, and that they will appear to follow one another at a uniform rate, and will accomplish the journey in exactly the same time, viz. one day, which is the time the earth takes to perform one rotation, so that there is no need of any connecting rod.

(3) We find, on careful measurement, that the earth is not exactly a sphere, but that it is slightly flattened at the poles and bulges somewhat at the equator. Thus a straight line through its centre from pole to pole is about 27 miles shorter than a straight line through its centre at right angles to the first straight

line. Geologists tell us that the earth was once soft and plastic; and if this were so, it has been calculated that a rotation about its axis would have caused it to assume the shape that it now has. Thus a rotation of the earth about its own axis will explain its present shape. (See par. 36.)

(4) If we observe those external bodies called planets, we find, by means of our telescopes, that each of them is a globe revolving around its own axis. Hence it seems very probable that the earth, which is a similar globe, will also revolve about its own axis.

The above are only reasons for believing that the earth rotates about its axis, but there are other evidences which amount to actual proofs.

1st Proof.—The top of a tower is farther from the centre of the earth than the bottom is, and hence in one rotation of the earth moves through a greater distance than the bottom does. Thus in Fig. 241, where TB is supposed to represent the tower, it is evident that in a revolution the top T will describe a larger circle than the base B, and so travel a greater distance. Now, as the top completes its revolution in the same time as the bottom, it is evident that it must move faster than the bottom. We suppose that the earth rotates from west to east, and, if this be so, the top of the tower moves eastwards faster than the bottom does. Thus if a stone be dropped from the top of a vertical tower it starts with an eastward velocity greater than that of the bottom of the tower, and as in its fall it preserves its greater velocity it should fall a little to the east of the bottom. This experiment was performed at Hamburg from the height of 250 feet, and the deviation was found to be 0·35 inch to the *east*. Hence we conclude that there must be a revolution of the earth *from west to east*. Let C (Fig. 241) be the centre of the earth, T the place from which the body is let fall, TB the vertical line in direction of the centre. When the body reaches the earth, let *tb* be the position of the vertical

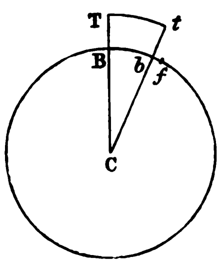


FIG. 241.

line in consequence of the earth's motion in the interval. Take B*f* = T*t*, and *f* will be the place of the body, because the body, leaving the top of the vertical with a motion equal to the motion of the top, is, at the end of its fall, as far from the first position of the bottom of the vertical as the top of the vertical itself is from its first position. But B*b* is less than T*t*, and therefore than B*f*, in the proportion of CB to CT; consequently *f* is to the eastward of *b*. This is on the supposition that the place is at the earth's equator, and it may suffice for an illustration.[1]

2nd Proof.—We take a long thread; fixing one end to the ceiling of a room or other convenient point of attachment, and fastening a heavy weight to the other, we form a pendulum. The string remains at first in a vertical direction. Now place a table under it and draw the weight towards you, and then let it go, so that it swings backwards and forwards through its former position. Care has to be taken at starting not to pull the weight sideways, or it will not swing back through its former position.

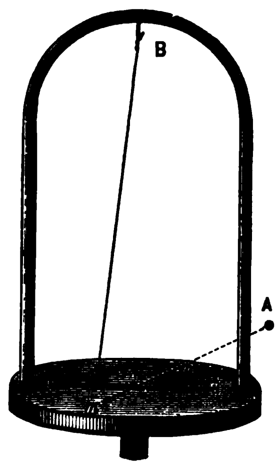


FIG. 242.—Pendulum experiment to prove earth's rotation.

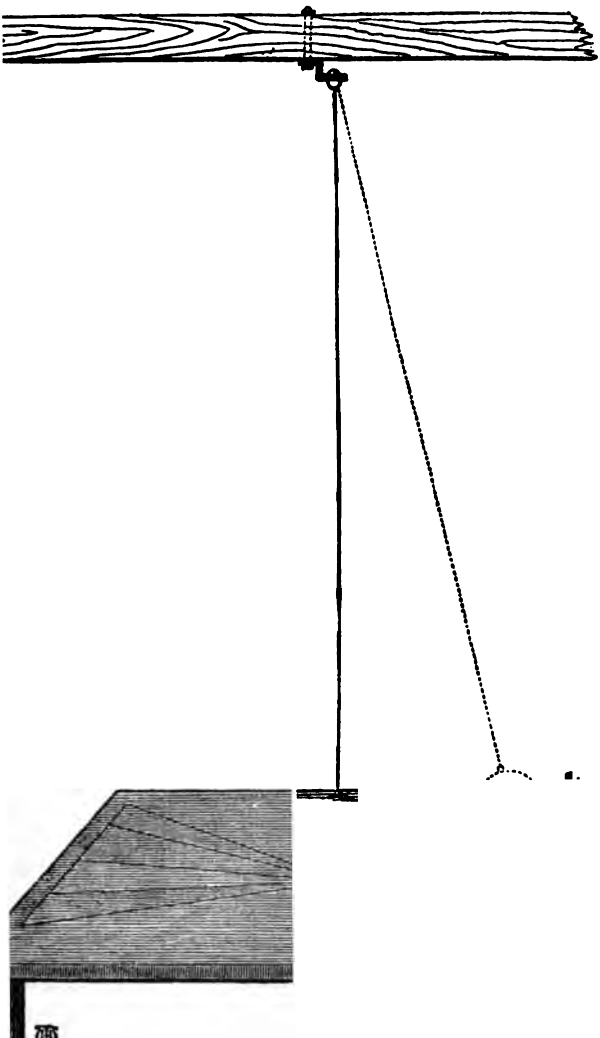
On the table mark the farthest position to which the weight swings at each end of its journey. We shall find that our marks on the table are slowly and regularly going round in the same direction as the hands of a watch. Hence the table must be moving, and therefore the earth is also moving. For it is easier for the thread or wire which supports the

[1] To find the exact time of the earth's axial rotation, we only require to determine the length of the sidereal day by finding the interval between two successive transits of the same star. Astronomers do this with the aid of a transit telescope, which is so mounted as only to move up and down in the meridian of the place where it is used. If an observer having an accurate watch, fix two strings or wires vertically at a short distance apart, and then, keeping them both in the line of sight, watch the same star cross them on two successive nights, he will find the time of the earth's rotation to be about 23 hours 56 minutes.

pendulum to twist than for the heavy weight to alter its course of swing.

The figure shows how this experiment may be carried out. B is the point of suspension of the pendulum, which hangs vertically over the point where the two lines *mn*, *uv* cross on the table. The pendulum is drawn out along the line *mn* to the point A, and then let go, swinging backwards along the line *nm*. It continues its oscillation backwards and forwards, but if watched it will be found that the direction of its oscillation is slowly twisting round from the position *nm* to *uv*—in fact, twisting round in the direction of the hands of a watch in the Northern Hemisphere, and in the opposite direction in the Southern Hemisphere. If the oscillation is kept up long enough, the plane of oscillation will make a complete circle. Now, it can be proved that a pendulum having a free motion at its pivot, when set swinging, keeps its direction in space, whatever change of position its support may undergo. Its change of path over the floor or table above which it swings must therefore be due to the rotation of the earth with the objects upon it beneath the pendulum. The fact that the plane of oscillation turns towards the right in the Northern Hemisphere, and in the reverse direction in the Southern, shows that the earth rotates from west to east. This experiment was first performed by Foucault, who swung a pendulum from the dome of the Pantheon at Paris in 1851. The rate of change in the direction of the plane of oscillation of a swinging pendulum decreases from the pole to the equator. At the pole it amounts to a complete circle in 24 hours, or 15° in one hour; at London it is a little over 11° in an hour; at Cairo about 8°; and at the Equator 0°.

3rd Proof.—The easterly direction of the trade winds can only be explained by supposing that the earth rotates from west to east. The currents of air passing towards the hotter parts of the earth undergo, in consequence of the earth's rotation, a deviation towards the right in the Northern Hemisphere, and towards the left in the Southern, so that winds from the north become north-east winds, and winds from the south become south-east winds. A deviation in certain ocean currents is also explained by the earth's rotation.



43.—Foucault's experiment in northern hemisphere, proving the rotation of the rth from west to east by the apparent deviation of the plane of oscillation of a *ndulum towards the right.*

We have thus sufficiently proved that the earth rotates on its axis once a day, and that this diurnal rotation gives us the daily risings and settings of the sun, moon, and stars—causing, in fact, the celestial sphere to revolve round an imaginary axis, which is the axis of the earth produced to the sphere of the heavens. One effect of this daily rotation of the earth is that the earth will evidently turn first one half and then the other towards the sun, and we get the ever-recurring phenomena of day and night. We will now, however, consider more particularly this rotation as far as it affects the motions of the stars at different distances from the poles.

272. **Daily Appearances of the Stars in Different Latitudes.**—Each place on the earth has its sphere of observation, with its own zenith and horizon. Imagine an observer at the north pole of the earth. Then the zenith or point straight overhead and the north pole of the heavens will coincide, and the true or rational horizon will coincide with the celestial equator. The heavens will appear to revolve round the zenith, each star describing a circle parallel to the horizon. These parallel circles increase in size as we pass from the pole to the equator. No star on this "parallel sphere" rises higher or sinks lower, and an object upon the equator will perform its diurnal motion round the horizon. One half of the heavens will be continuously visible, turning round once each day, and the other half below the horizon will never be visible.

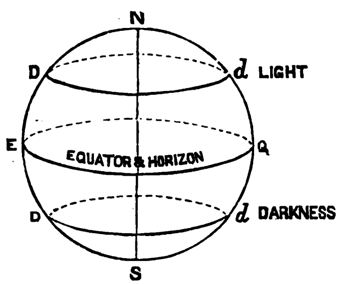


FIG. 244.—Parallel sphere, with pole at zenith, and celestial equator for horizon.

Let us consider the appearances to an observer on the equator (Fig. 245). C is the observer; N and S the points on the horizon respectively north and south. E is his zenith. The celestial equator is the circle passing through EQ, being, of course, vertical to his horizon, and perpendicular to NS, which is parallel to the earth's axis. The heavens seem to

volve about this axis NS, and thus stars rise on all parts of
.e eastern horizon, describe circles parallel to the equator,
ıd set in the west. Every
:ar rises in some part of
he day, and sets twelve
ıours later, describing a
semicircle above the horizon,
these semicircles getting
smaller and smaller
the farther the star is to
the north or south.

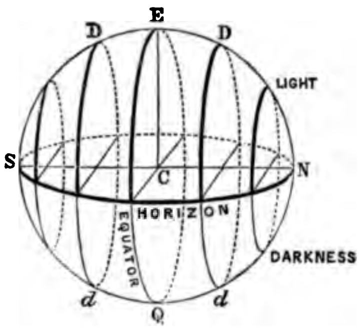


FIG. 245.—Right sphere: poles on horizon.

Let us now consider
:he appearances to an observer
who is between the
:quator and the north pole
Fig. 246). The celestial sphere has this appearance. N is
he north pole; EQ the circle of the equator, intersecting the
orizon obliquely, HO being the horizon. The heavens appear
ɔ revolve about an axis passing through the centre of the
ɔhere and through N, this
eing at right angles to the
ꝗuator. All stars appear to
escribe circles, like *d*D, paral-
:l to the equator. It will be
ɔticed that the stars to the
ɔrth of the equator are above
ıe horizon for the greater part
˙ their path, below it for the
naller part. On the southern
de of the equator the reverse
the case; they will be above
for the smaller part, below

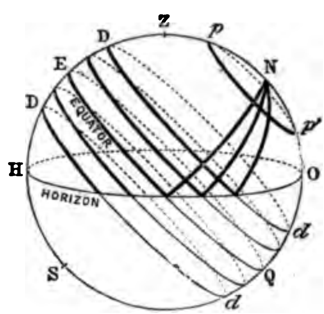


FIG. 246.—Oblique sphere at mid-latitude.

for the greater part. A star above O will describe a path,
ːe *pp'*, such that it is never below the horizon, thus never
sing nor setting. These stars are called *circumpolar stars.*
:ars below H never appear above the horizon, and so are
ɜver seen. The greater part of the heavens are visible at
›me *time of a complete* day, the parts below H being the

only parts never above the horizon. These parts are, of course, just equal in extent to the parts above O, that is, the parts in which are the circumpolar stars which never set. We get similar appearances at different positions in both the Northern and Southern Hemispheres, the only difference being that the nearer we go to the equator the lower the celestial pole is, and consequently the fewer circumpolar stars there are, and the fewer stars which are never visible.

In fact, the celestial equator is inclined to the horizon, at all latitudes between the equator and the pole, at an angle equal to the distance of the poles from the zenith. Fig. 246 is drawn for latitude 45° N., and Fig. 228 is drawn for the latitude of London, $51\frac{1}{2}$° N.

The appearances of the stars, then, owing to the daily rotation of the earth, are different at different parts of the earth.

(1) At the poles stars never rise or set, and the same half of the heavens is continuously visible.

(2) At the equator all stars rise and set, and in one complete day the whole heavens have been visible.

(3) Between the poles and the equator we have stars which rise and set, circumpolar stars that never set, and stars which never rise, the parts of the heavens in which these last are being the only parts never visible.

The number of circumpolar stars, and of those that never rise, increases as we take positions further from the equator towards either pole of the earth.

The student should practise drawing a diagram of the celestial sphere for any latitude, and then indicate upon it the diurnal path of stars having a given declination or distance from the equator. To do this, draw a complete circle to represent the meridian of the celestial sphere, the observer being at the centre of this sphere. A horizontal great circle (shown as a flat ellipse) bisecting the meridian will represent the rational horizon. The horizon meets the meridian at the north and south points, and divides the celestial sphere into a visible half and an invisible half. The zenith will be 90° above any point on the horizon, that is 90° from the north or

south points, and the nadir will be 90° below the horizon. Remembering that the elevation of the pole is equal to the latitude of the place of observation, find a point as many degrees above the *north* point of the horizon as the observer's latitude, and this will give the north pole of the heavens. The south pole of the heavens will be just as far below the southern point of the horizon as the north pole is above the north point of the horizon. To obtain the celestial equator, draw a great circle 90° from the poles, dotting the half on the west side of the horizon. The points where the celestial equator cuts the horizon are the east and west points (see Fig. 228). To draw the diurnal path of a star whose declination is 30° N., draw a circle parallel to the equator at this distance above the equator, and the required path is obtained. To draw the diurnal path of a star with declination 75° N., we require a parallel circle at this distance north of the equator. For a star with declination 60° S., we require a circle parallel to the equator at this distance south of it. Where the diurnal circles of the stars meet the horizon indicates their rising and setting points. The angular distance of the rising point of a star from the east gives the *amplitude* of the rising star, while the distance of its setting point from the west gives the amplitude of the star at setting. If a star's diurnal circle does not intersect the horizon, it is the diurnal circle of a circumpolar star if its declination is north; it is the diurnal circle of a star that is never seen north of the equator, if its declination is south.

Fig. 228 is drawn for the latitude of London, $51\frac{1}{2}$° N. MM′ is the celestial equator, and a star or other heavenly body on the equator has declination 0°. It rises exactly in the east, and sets exactly in the west. A star rising at *e* between the east and north has a declination, the arc M*m*, of about $23\frac{1}{2}$°, and is carried to its highest point at *m* on the meridian, and then descends to set at *w*, between the west and north. More than half its diurnal circle is above the horizon. The stars rising at N and *s* are circumpolar stars, describing the whole of their diurnal circles above the horizon. They culminate or reach their highest point on the meridian at N′ and *s*′ respectively. The arc MN′ is about 40°, and this gives the north

declination of the star whose path is the circle NN′. What is the north declination of the star whose path is represented by *ss′*? The star rising at *f* culminates on the meridian at *n* and sets at *v*, only a small part of its diurnal circle being above the horizon. What is the south declination of this star? The paths of two other stars that are never visible in the Northern Hemisphere are shown. Find the south declination of each.

From our study of the paths of the stars, we can add to the numbered statements already made the following:—

(4) At all latitudes in the Northern Hemisphere between the poles and the equator, the stars whose distances from the north pole are less than the latitude of the place are circumpolar stars, the stars whose distances from the opposite pole are less than the latitude of the place never become visible, while stars included between these limits rise and set. The daily courses across the heavens of the stars that rise and set are greater or less than 12 hours, according as they have north or south declination, for it must be remembered that the daily courses of all stars, however great or small their diurnal circles, are accomplished in the same time, viz. 24 hours.

273. **Yearly Changes in the Appearance of the Sun.**—*Revolution of the Earth.*—Besides the daily rotation of the earth and its effects in producing an apparent daily motion of the sun and stars, we will consider another apparent motion of the sun. If we observe, for many nights in succession, the stars which first appear on the horizon in the west after sunset, we shall find them to be slowly and continually changed. Those stars which we first saw on the horizon after sunset will be found to have set before the sun, and other stars will be on the horizon which formerly appeared higher up in the heavens. If we observe the east also we shall find that those stars which we saw first on the horizon at the beginning of our observations are higher in the heavens when they have become visible after sunset. The longer we continue our observations the higher will the last-mentioned stars appear, and in the course of some months the first-mentioned stars, which have set in the west before sunset, will reappear in the east after sunset. These effects can be explained by supposing that the sun has a

motion from west to east round the heavens, passing over the stars. This motion is quite independent of the daily motions which affect the sun and stars alike. It is a slow motion—in fact, we should have to watch a whole year to see one revolution completed. Thus we have an apparent motion of the sun round the heavens in one year's time. However, we remember that there was an apparent daily motion of the sun round the earth from east to west, which was found to be not a motion of the sun, but a daily revolution of the earth from west to east, which gave an apparent motion to the sun in the opposite direction, viz. from east to west. Is this yearly motion of the sun real, or only an apparent motion of the sun due to some rotation of the earth? To answer this we must see if there is any possible motion of the earth which would give us such an apparent yearly motion for the sun. We remember that it has a daily revolution on its axis from west to east, which made the sun seem to revolve daily from east to west; it could not have also a yearly revolution on its axis which could give this fresh yearly motion to the sun. But instead of the sun moving round the earth in a year, the earth could move round the sun in a year. We must see if this supposed motion of the earth would explain the apparent motion of the sun. But we must remember that it is a yearly motion, quite independent of the daily revolution of the earth, and for the present we may leave out of consideration the daily motion. We will first take the supposition that the sun moves round the earth from west to east amongst the stars.

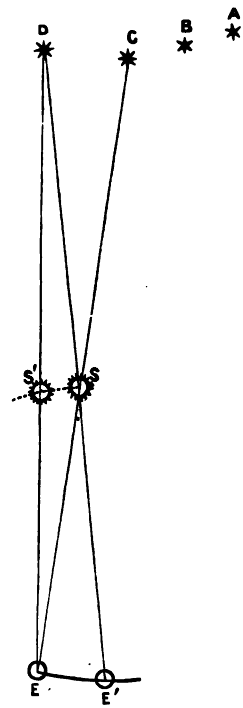


FIG. 247.

Let S represent one position of the sun, E the position of the earth, A, B, C, D, stars beyond and behind the sun.

(These stars would not be visible in the sunlight, but we know they must be there, for we can see them at another part of the year when the sun is not in that part of the sky.)

When the sun is at S it appears in front of the star we call C; in a few days it seems to move eastward to S′, when it is in front of the star D, and then seems to continue in its eastward motion till finally in a year's time it has again come round to the position S. But this apparent motion of the sun is equally explained by supposing the sun fixed at S, and the earth to move from E in the opposite direction—*i.e.* westward.[1] Thus when the earth is at E, the sun, now supposed fixed at S, appears in front of the star C; when the earth has moved to E′, the sun at S appears in front of the star D; and as the earth moves gradually westward from E to E′, the sun will appear to move eastward, passing from its position in front of the star C till it appears in front of the star D. Thus a real motion of the earth westwards gives an apparent motion to the sun eastwards. If the earth complete its journey round the sun in one year, the sun will appear to move round the heavens in a year also.

Therefore we see that the apparent yearly motion of the sun round the heavens can be explained either by supposing the earth moves round the sun or the sun round the earth. We have to decide which is the correct supposition.

From our experiences of the train, and conclusion with regard to the daily revolution of the earth, we know that if the earth and all it contains move smoothly, then our sensations will not tell us that we are in motion. Thus the earth may be moving round the sun, although we do not feel the motion. For this motion we shall, as before, give as evidence both *reasons and actual proofs.*

274. **Reasons for believing the Earth revolves**—

(1) We find out that the sun is more than a million times as large as the earth, so it would seem more reasonable that

[1] Westward—*i.e.* from left to right, when we consider the motion from the earth, and looking towards the sun; but looking from the sun at the earth it would appear to move from right to left—*i.e.* eastward, round the sun. In the text we continue to speak of it as a westward motion.

the small earth should move round the large sun than that the sun should move round the earth.

(2) We have once before mentioned the planets. These are bodies which appear to the eye like stars, but which, on being closely watched for long periods, seem to wander amongst the rest of the stars in peculiar ways, sometimes advancing, at other times receding, and at other times remaining stationary. There are five such planets visible to the naked eye, and more visible to the telescope. Through the telescope, two of those five are particularly noticeable for presenting phases like the moon; and these two, moreover, at rare intervals, have been seen to pass as black dots across the sun. All these peculiarities of motion and of phases can be easily explained by supposing that these planets revolve round the sun at different distances and in different periods, and that the earth is only another planet, also revolving round the sun at its own distance and in its own period. No other theory will sufficiently explain all these appearances of the planets, therefore it seems likely that this revolution of the earth round the sun is the true theory.

275. **Proofs of the Revolution of the Earth.**—We cannot, as we did before for the daily rotation, find direct proofs on the earth itself for the yearly revolution round the sun; we must look to outside bodies. In one of the following proofs the question of the velocity of light occurs; hence we premise the statement that the velocity can be measured by instrumental means on the earth itself, and is found to be about 186,000 miles per second.

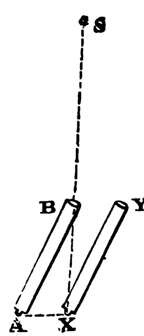


FIG. 248.

Proof I. Aberration of Light.—Let us suppose that we want a drop of water to fall down a tube without wetting its side. If the tube is at rest, we hold it vertically in the direction XS. If the tube is moving, it must be held slanting, so that the drop falls in at the top when the tube is at AB, and falls down to A while the tube has moved forwards to XY. The faster the tube moves the more must we slant it in order that the drop may fall down. So it is with the light from a star. If we were

motionless we must point our telescope directly at the star, but if we were moving we must slant our telescope so that the ray of light may proceed down it. We find that this slanting of the telescope varies throughout the year, and that the star appears to revolve in a circular motion round what we know is its true position. This apparent revolution of the star must be caused by a revolution of the earth.

Let us consider this further, for we repeat that this displacement or aberration (Lat. *erro*, I wander) of a star can only be due to the combination of the orbital motion of the earth with the motion of light. It is perhaps the most convincing proof that the earth revolves round the sun, and not the sun round the earth. Thus when the earth is at the point A in its orbit (Fig. 249), and moving perpendicularly to a star situated at S^1, this star is displaced in the direction of the earth's motion, and is seen at S^2. The amount of this displacement is a small angle of 20·5″, and is dependent on the proportion between the earth's orbital velocity and the velocity of light. As the earth proceeds in its orbit the star keeps, as it were, before it, describing, in fact, a small elliptical orbit round its true position. The longer axis of this aberration ellipse is always 41″, or twice the angle of displacement, 20·5″; but the shorter axis of the aberration ellipse depends on the position of the star with reference to the plane of the earth's orbit, the ellipse becoming more and more flattened as the star approaches this plane. If the star is in the plane of the earth's orbit, so that its celestial latitude is zero, the aberrational displacement is a mere line. The value of the small angle of displacement, called the "constant of aberration," enables us, from the known velocity of light (186,000 miles per second), to calculate the velocity of the earth in its orbit, and from that to find the distance of the sun.

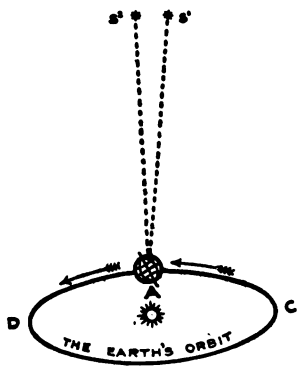


FIG. 249.—Aberration of a fixed star.

average velocity of the earth in its orbit is found to be 18·5 per second, and the mean distance of the sun is then d to be about 93,000,000 miles.

Proof II.—If we look at a distant object from a fixed ion, it appears thrown or projected the sky or other background at rtain point. On changing our ion and looking at the same ob- it appears to meet the sky at a ent point. This apparent dis- ment of an object observed due real change in the position of the ver is called the *parallax* of the t, and the angle whose vertex is e centre of the object observed, whose sides pass to the two points

FIG. 250.—Aberration ellipses of stars in different celestial latitudes.

FIG. 251.—Parallax of fixed stars. Half the angle shown is the annual parallax.

servation, is called the *angle of parallax.* Now, if we to look at any of the fixed stars from a certain point e earth, and then could instantly pass to the other end at diameter of the earth, nearly 8000 miles away, we

could not detect any parallax for a star, so vastly distant are they. Even when viewed from opposite sides of the earth's orbit, 186,000,000 miles apart, most of the fixed stars are so distant that they do not suffer any apparent displacement. A few, however, do show a slight parallax, and this is another proof of the earth's revolution round the sun. Fig. 251 illustrates the parallax of certain fixed stars, though the size of the earth's orbit in relation to the distance of the stars is greatly exaggerated. The angle formed by two lines passing to a star, one from the centre of the earth's orbit, and the other from a point on the orbit, is called the *annual parallax* of the star, *i.e.* it is the angle subtended at the star by the radius of the earth's orbit. The annual parallax of certain fixed stars is a proof of the earth's revolution round the sun. (Those stars that have an annual parallax appear to describe a small ellipse each year, but this ellipse must not be confounded with the aberration ellipse, for its cause is quite different; its size varies with the amount of annual parallax, and the motion is in an opposite direction to that of the earth.)

276. **The Earth's Orbit.**—The earth's orbit, as we have said, is its path round the sun. This path is in one plane, and is very nearly, but not exactly, a circle. It is strictly an *ellipse*. An ellipse can be thus described. Two pins, *s* and *s'*, are stuck in a piece of paper, and a loop of cotton put over them. This loop is tightened by a pencil at P, and, keeping the loop tight, the pencil on moving round the pins will describe the ellipse PP'*ab*AB. *s* and *s'* are called the *foci* of the ellipse.

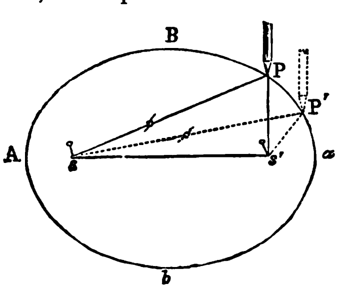


FIG. 252.—Showing how an oval or ellipse can be marked out.

In the case of the earth's orbit the foci are comparatively close together, and hence this ellipse looks almost like a circle. The sun occupies one of these foci, and thus the earth is not always *at the same* distance from the sun. At the shortest distance

the earth is said to be in *perihelion* (near the sun); at the furthest distance it is in *aphelion* (away from the sun). These positions of the earth occur respectively on January 1 and July 1 (see Fig. 277).

We may remark that, though the earth's orbit is elliptical, yet it approaches so near a circle that if we were to represent it to exact scale in this book, the figure would be indistinguishable from a circle.

The *eccentricity* of an ellipse is the displacement of a focus from the centre, and is expressed by a fraction with this distance for the numerator and half the major axis for the denominator. The smaller this fraction, the nearer is the ellipse to a circle. The eccentricity of the earth's orbit is only about $\frac{1}{60}$.

The earth is one of eight planets revolving round the sun in elliptical orbits.

277. **Kepler's Laws.**—Kepler's First Law states: "The earth and the other planets revolve in ellipses with the sun in one focus." Newton explained this law by showing that the force acting on each planet varies inversely as the square of its distance from the sun.

Kepler's Second Law states: "The radius vector of each planet moves over equal areas in equal times." Newton concluded from this that the force causing a planet to describe its orbit is a central force always acting along the radius vector in the direction of the centre of the sun.

Kepler's Third Law states: "The squares of the periodic times of the planets are in proportion to the cubes of their mean distances from the sun." This law was explained by Newton's conclusion that the force of the sun's gravitation on a planet varies directly as the planet's mass, and inversely as the square of its distance from the sun.

We have just explained the nature of an ellipse, and we will now illustrate the meaning of the second law, which will enable us to understand the nature of the earth's motion in its orbit. (The third law does not concern us at present.)

Let Fig. 253 represent the earth's elliptical orbit, with S for the sun in the focus. AB is the major axis of the ellipse,

and a line at right angles through the centre would be the minor axis. Let the earth start from A, the nearest position to the sun (*perihelion*), and move to C. The radius vector, or line joining the centre of the sun and planet, sweeps over the area ASC. Now suppose the earth has moved to B, the point farthest from the sun (*aphelion*), and let it move onward from B to D in the same time that the earth took to move from A to C. Then the law of equal areas states that the area BSD is equal to the area ASC. Now, the distance AC is plainly greater than the distance BD, and as these distances are passed over in equal times, the velocity of the earth must be greater the nearer it is to the sun. In fact, the velocity is greatest at perihelion, decreases continually till the earth arrives at aphelion, and then increases until perihelion is again reached.

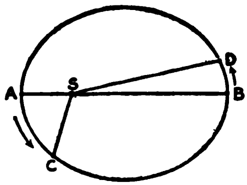


FIG. 253.—Illustrating Kepler's second law.

We have thus learnt three things about the earth's orbit:—

(1) It is in one plane.

(2) It is an ellipse of small eccentricity, with the sun at one focus.

(3) The earth's velocity in its orbit is not constant, but varies.

278. **Observations relating to the Earth's Orbit.**—How can we learn—

(*a*) that the earth's orbit is in one plane?

(*b*) that the orbit is not circular, but elliptical?

(*c*) that the speed of the earth in its orbit varies?

(*a*) We know that the earth's orbit is in one plane because the apparent annual path of the sun through the stars (due to the earth's revolution round the sun) is in one plane, the sun having been observed to move along the same great circle of the heavens, the ecliptic, year after year. In fact, careful observations have shown that the centre of the sun always appears to move along the ecliptic, and therefore the earth's orbit must lie in the plane of the ecliptic.

(*b*) We know that the earth is not always at the same

distance from the sun, as it would be were the orbit circular with the sun in the centre, because the sun looks bigger at one time of the year than at another. In fact, the sun's apparent diameter varies regularly during the year, and as there is no reason to believe that the sun himself varies thus regularly in size, we must change our distance from it in a manner indicated by this apparent change of size. The sun's apparent diameter is the angle which its diameter subtends at the eye of an observer on the earth, and we know that the apparent diameter of an object is inversely proportional to the distance of the object.

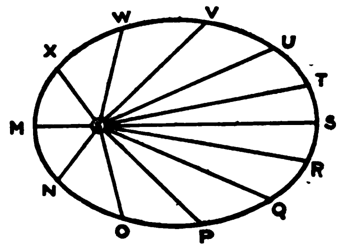


FIG. 254.—Illustrating how the shape of the earth's orbit is found.

The sun's apparent diameter is greatest on January 1, and least on July 1, and we may thus learn that the earth is nearest the sun on January 1, and most distant on July 1. We may learn more from the actual measurements on these dates. The apparent diameter of the sun when greatest is $32' \ 36''$, and when least $31' \ 32''$, and hence the ratio of the distances is inversely proportional to the fraction $\frac{32' \ 36''}{31' \ 32''} = \frac{1956}{1892} = \frac{31}{30}$ nearly; that is, the sun is about $\frac{1}{30}$ of its mean distance *nearer* on January 1 than on July 1 (see Fig. 255).

Careful measurements of the sun's diameter have been made from day to day, and from these measurements it is possible to construct the earth's orbit, and to show that it is an ellipse, with the sun in one of the foci. To do this we draw from a point lines SM, SN, SO, SP, etc., making the lengths of the lines inversely proportional to the apparent diameter of the sun at the times of observation, and the direction of the lines correspond to the sun's angular position at the time of observation. On joining the ends of the lines, the figure of an ellipse is traced out (see Fig. 254, where, however, as in other figures of the orbit, the ovalness is much exaggerated).

(*c*) Careful observations of the apparent motions of the sun along the ecliptic through the fixed stars show that the angular distance moved through varies slightly from day to day, and we deduce from this that the earth's velocity in its orbit varies. In the course of a year of a little more than 365 days the sun returns to the same point from which it started, so that it must have passed through 360° in the time stated. Its average daily motion is thus a little less than one degree. Now, it is found that the sun moves through an arc of 1° 1′ 10″ in twenty-four hours when it is nearest to the earth

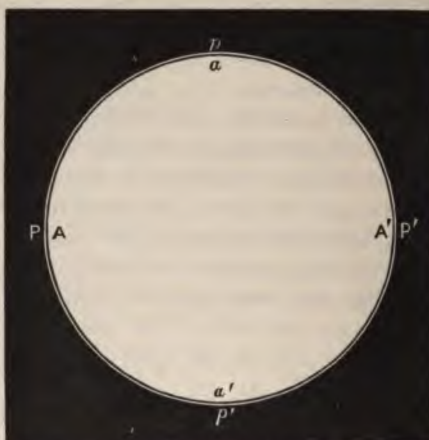


FIG. 255.—Sun's annual apparent change of diameter. P*p*P′*p*′, sun's disc at perihelion; A*a*A′*a*′, sun's disc at aphelion.

on January 1, and that on July 1, when farthest from the earth, it only moves through an arc of 57′ 11·5″. Thus actual measurement shows that the rate of the earth's motion in its orbit changes, being greatest when near the sun, and least when most distant.

A further proof of this variation of velocity is found by showing that it is a necessary consequence of the law of gravitation that the speed of the earth in its orbit must be such that the radius vector or line joining the earth and the *sun must* describe equal areas in equal times.

279. **Different Kinds of Day.**—We know that the sun, in consequence of the earth's revolution round it, seems to move eastward among the stars. A star reaches its greatest altitude, or transits the meridian, at exactly the same interval each day. A *sidereal day* is the interval between two successive meridian passages of the same star. It is the actual time taken by the earth to make a complete rotation (360°) upon its axis. A *solar day* is the interval between two successive passages of the centre of the sun across a meridian, and it is *noon* at the moment of transit. If the sun, like a star, appeared always at the same place in the sky, a solar day would be of the same length as a sidereal day. But the sun seems to move eastward among the stars at the rate of about 1° per day, so that the earth must rotate nearly 361° about its axis before a given meridian comes opposite to the sun again, and so the solar day is nearly four minutes longer than the sidereal day.

By the help of Fig. 256 we can illustrate why the solar day is longer than the sidereal day. M represents the centre of the sun, while the stars are at so great a distance that the rays from them are sensibly parallel. E_1 and E_2 represent two positions of the earth in its orbit at the interval of a sidereal day, or after one complete axial rotation. PA is the meridian of a place A on the earth. At E_1 the sun and a distant fixed star are on the meridian of A at the same time. At E_2 when the earth has made one complete rotation on its axis the distant fixed star is on the meridian of A again, but the earth must continue to turn through the small angle represented by the arc AB before the sun is again on the meridian PA. Hence the solar day or time from noon to noon is longer than the sidereal day.

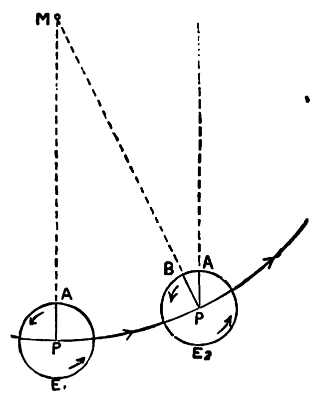


FIG. 256.—Diagram showing how the difference between the sidereal and solar day arises.

As the sidereal day is shorter than the solar day by about four minutes, we find that there are 366¼ sidereal days during the 365¼ solar days of a year, *i.e.* there is one more rotation of the earth than there are days in the year.

The sidereal day, measured by the rotation of the earth on its axis, is of invariable length. But the solar day, measured by the interval between two successive appearances of the sun upon the meridian of any place, varies in length, because the varying speed of the earth in its orbit causes the distance of its forward movements in the orbit to vary, and thus the earth does not turn on its axis through the same angle every day to bring the sun on a meridian. Hence the *apparent* or *true solar day*, as the solar day that appears as the actual result of two successive meridian passages of the sun is called, varies in length at different parts of the year. It is longest when the sun moves fastest, and shortest when the sun moves slowest in its orbit. Another cause, the apparent movement of the sun in a path inclined to the meridians at varying angles, leads to an inequality in the length of the apparent solar days.

Solar time thus seems to be unsatisfactory, owing to its want of uniformity, and yet our ordinary life is regulated by the sun. To get over the difficulty, and obtain a uniform measure of time, we take the average of all the apparent solar days of the year, and call this a *mean solar day.* We imagine a sun called the *mean sun* moving uniformly along the celestial equator and completing its yearly circuit of the heavens in the same time as the actual sun. A *mean solar day* is therefore the average of the apparent solar days, and is always of the same length. This is the day which our clocks and watches keep, and it is divided into 24 hours, and these into minutes and seconds, so that our ordinary timepieces keep *mean solar time.* Greenwich mean time is used in all parts of England, and this is the time as shown by a clock moving through 24 solar hours in the *average* interval between two successive passages of the sun across the meridian of Greenwich, the moment of passage being *Greenwich mean noon.*

Such a clock does not always indicate noon when the real

sun crosses the meridian, being generally a little before the sun or after it. True or apparent noon is found by ascertaining the exact moment of the meridian passage of the sun by a transit telescope. True time is also indicated by a sundial. The difference between true or sundial time, and the time shown by a clock keeping mean solar time, is called the *equation of time.* It is used to regulate the clock, for sundial time, plus or minus the equation of time, gives the clock time.

The *civil day* is the mean solar day and the day of ordinary life. It begins and ends at midnight. The *astronomical day* begins at mean noon, twelve hours later, and is reckoned round through 24 hours. Thus 4 A.M. of Friday, May 19, civil time, is Thursday, May 18 16 hours, by astronomical time.

The word "day" is also often used for *daylight*, or the time during which the sun is above the horizon of a place.

280. **Definition of Terms.**—The *ecliptic* is the great circle which the sun appears to describe round the heavens once a year. It is so called because all the eclipses of the sun and moon occur in it.

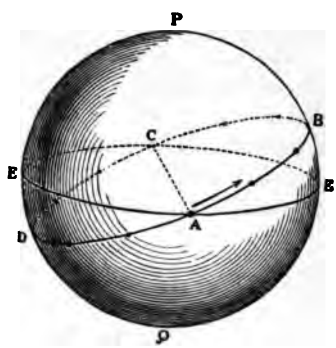


FIG. 257.—Diagram of the celestial sphere, showing the celestial equator EE intersected by the ecliptic DB at the nodes A and C. A is the vernal equinox, C the autumnal equinox, B the summer solstice, and D the winter solstice. The arrow shows the direction of the sun's apparent annual motion on the ecliptic. The angle BAE is the obliquity of the ecliptic.

The *plane of the ecliptic* is the plane passing through this circle, or, what is the same thing, it is the plane in which the orbit of the earth lies—for this orbit, we remember, is in one plane.

The *plane of the equator* is the plane passing through the earth's equator, this plane being supposed to be continued outwards to the sphere of the heavens, which it will cut in the celestial equator. The axis of the earth will, of course, be at right angles to this plane. These two planes do not coincide with one another, but intersect at two nodes or crossing-points, 180° apart, the angle of intersection being $23\frac{1}{2}°$ (see Fig. 257).

The *equinoctial points*, or *equinoxes*, are the two points where the ecliptic cuts the celestial equator. The sun is at these points on March 21 and September 23.

The *obliquity of the ecliptic* is the angle which the plane of the ecliptic makes with the plane of the equator at the equinoctial points. Its value is about $23\frac{1}{2}°$.

The *solstices* are the two points of the ecliptic midway between the equinoctial points. When the sun in its motion on the ecliptic reaches the solstitial points, it has its greatest declination, or greatest distance from the equator. On June 21 it is at the summer solstice, and has its greatest northern declination; on December 22 it is at the winter solstice, and has its greatest southern declination (see Fig. 259).

The *tropics* are two great circles drawn through the solstices parallel to the equator. They are so called (Gk. *tropo*, I turn) because the sun then turns from its northward motion to the south, or *vice versâ*. The northern tropic is the Tropic of Cancer, and the southern tropic is the Tropic of Capricorn.

The *zodiac* is a belt of the heavens 16° wide, 8° on each side of the ecliptic. It is so called (Gk. *zoon*, an animal) because the groups of stars or constellations in it are figures of animals. The zodiac is divided into twelve equal arcs or parts, called *signs*, each 30° in length. The names of the signs are contained in the following lines :—

"The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin, and the Scales,
The Scorpion, Archer, and He-goat,
The Man that bears the watering-pot,
And Fish with shining tails."

Their Latin names, with the symbols used for them, and the days on which the sun enters the different signs, are as follows :—

NORTHERN SIGNS OF ZODIAC.

Spring Signs.

♈ *Aries*, the Ram, March 21.
♉ *Taurus*, the Bull, April 19.
♊ *Gemini*, the Twins, May 20.

Summer Signs.

♋ *Cancer*, the Crab, June 21.
♌ *Leo*, the Lion, July 22.
♍ *Virgo*, the Virgin, August 22.

SOUTHERN SIGNS OF ZODIAC.

Autumnal Signs.

♎ *Libra*, the Balance, September 23.
♏ *Scorpio*, the Scorpion, October 23.
♐ *Sagittarius*, the Archer, November 22.

Winter Signs.

♑ *Capricornus*, the Goat, December 21.
♒ *Aquarius*, the Waterman, January 20.
♓ *Pisces*, the Fishes, February 19.

281. **Yearly Changes in the Appearances of the Stars.**—If we look out at the same hour of the night, but at different times of the year, we shall find that the same stars are not visible in the same positions. We shall see this more clearly if we fix on any one star, and watch for its appearance on successive nights. On each succeeding night it rises some four minutes sooner and sets four minutes sooner than it did the night before. Thus, if in spring at nine o'clock it is just rising, it will be high up in the heavens at the same hour in summer, and in autumn it will be setting at the same hour. During the winter months it will be below the horizon at this hour, and we should have to wait for some time for it to rise. As spring comes on again it will rise earlier and earlier, till on the same day of the month as we first began observing it, it will rise at nine o'clock. So it is with all the stars.

These changes are closely connected with that change of the sun previously mentioned, viz. that the sun appears to move eastward amongst the stars. Hence the stars must seem to pass westward behind the sun, and as our day and night depend on the light from the sun, the stars on each successive night will appear to be slightly to the westward of the position they

occupied at the same hour on the previous night. Thus stars will rise earlier and set earlier on successive nights, the amount, viz. four minutes, being such that in a year's time they come back to the same positions at the same hours, for 365 times four minutes make up one day nearly. These yearly changes,

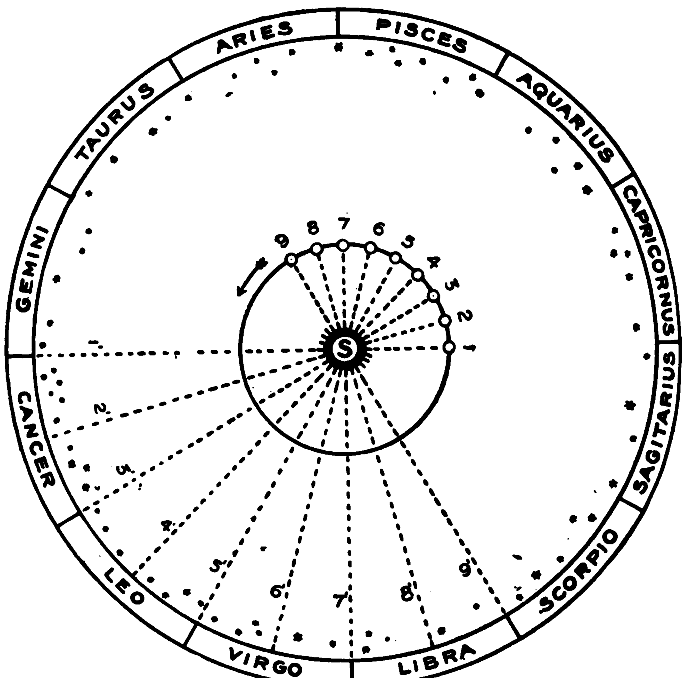


FIG. 258.—Illustrating the sun's apparent yearly path through the signs of the zodiac.

of course, are due to the revolution of the earth round the sun, as we showed previously in considering that revolution.

The apparent yearly motion of the sun through the various signs of the zodiac, and the different stars visible from the earth at midnight, are illustrated in Fig. 258. Let S represent the sun, and let the figures 1, 2, 3, 4, 5, 6, 7, 8, 9, indicate nine *positions* of the earth in its orbit, at intervals of about two *weeks apart*. Round the sphere of fixed stars are indicated the

signs of the zodiac. When the earth is at 1, an observer will see the sun in the direction 1 S among the fixed stars at 1′. The sun appears to be entering the sign Cancer. At midnight on the part of the earth turned away from the sun, the stars in the opposite part of the celestial sphere are visible. When the earth has moved to position 2, the sun appears among the stars 2′, about the middle of the sign Cancer, and the stars in the opposite sign Capricornus appear at midnight on the part of the earth turned from the sun. On the earth reaching the position 3, the sun is about to enter the sign Leo. Passing through the successive positions 4, 5, 6, 7, 8, 9, the sun will appear among the stars 4′, 5′, 6′, 7′, 8′, 9′, and the motion of the earth continuing all the way round its orbit, the sun appears to pass through all the signs of the zodiac, and to complete the circuit of the heaven on again reaching the position 1.

(In ancient times, the constellations or groups of stars opposite each arc or sign of the zodiac was of the same name as the sign, but, owing to a backward movement of the sign Aries, this sign is now in the constellation Pisces, the sign Taurus in the constellation Aries, and so on. It is thus necessary to distinguish between the *signs* of the zodiac and the *constellations* of the zodiac.)

We have as yet only considered the effects of the rotation and revolution of the earth so far as they effect the appearances of the stars. But these two motions have important effects on the appearances of the sun, and these we will now proceed to consider.

282. **Changes in the Declination and Right Ascension of the Sun.**—If we find with a suitable telescope the declination and right ascension of the sun day by day, we shall learn that neither of these quantities remains constant. At the spring or vernal equinox on March 21, the sun is crossing the equator to the north, and its declination is zero. In about a month the sun has moved along the ecliptic, and its northern declination has been increasing. Drawing a quadrant from the pole perpendicular to the equator, we see that this declination is represented by the arc SM (Fig. 259). At the end of another month, the declination will be again represented by the perpendicular

from its position to the equator. At the end of the third month it has reached its greatest northern declination, $23\frac{1}{2}°$, represented by the arc KQ, and is at the summer solstice. Its polar distance is also now least. It now begins to approach the equator again (the distance between the two dotted portions of the ecliptic and the equator gets smaller), until at the autumnal equinox on September 23 the declination is again zero. After

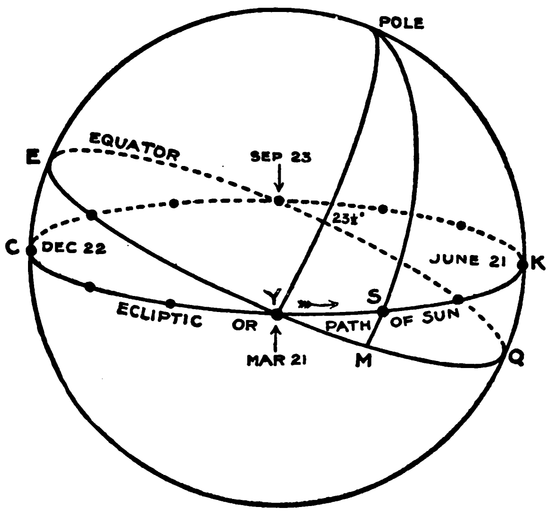


FIG. 259.—Diagram of celestial sphere, showing sun's position on the ecliptic at intervals of one month.

this date the sun passes south of the equator, and its southern declination increases until it reaches the winter solstice on December 22. The arc CE, $23\frac{1}{2}°$, represents its greatest southern declination, and the sun's polar distance is now greatest. After the winter solstice the sun in its path again approaches the equator, and comes back again to the vernal equinox.

Consider now the changes in right ascension, which is the angular distance of a heavenly body *east* of the vernal equinox, or first point of Aries, *along the equator*. On March 21 the sun is at the first point of Aries, ♈, and the right ascension is zero.

Next day the sun will be found about 1° to the east, and each day the right ascension increases about 1°. At the end of a month the right ascension will be the arc YM, about 30°, or the value of this arc in time. (Right ascension is usually expressed in almanacs in time, and not in degrees—1° = 4 minutes.) At the end of three months the right ascension is the arc YQ, or 90°. On September 23 the R. A. of the sun is 180°; on December 22 it is 270°; and it goes on increasing, for it is measured all round, until the sun reaches the vernal equinox again.

As already pointed out, the sun does not move along the ecliptic at a uniform rate, and therefore the daily change in the right ascension of the sun is not uniform. It is the change of the sun's right ascension compared with the fixed R. A. of the stars that leads to the difference between the solar day and the sidereal day, and it is the varying amount of the sun's R. A. that causes the true solar days to be of unequal length.

Summarizing, we find that—

(*a*) On March 21 the sun crosses the equator through the first point of Aries, and it is the Vernal Equinox.

Sun's R. A. = 0, and its **Decl.** = 0.

(*b*) On June 21 the sun has described an arc of 90° along the ecliptic, and it is the date of the Summer Solstice.

Sun's R. A. = 90° or 6 hours, and its **Decl.** = $23\frac{1}{2}$° N.

(*c*) On September 23 the sun has described an arc of 180°, is at the first point of Libra, and it is the date of the Autumnal Equinox.

Sun's R. A. = 180° or 12 hours, and its **Decl.** = 0.

(*d*) On December 22 the sun has described an arc of 270°, and it is at the Winter Solstice.

Sun's R. A. = 270° or 18 hours, and its **Decl.** = $23\frac{1}{2}$° S.

(*e*) Finally, on March 21 of the next year the sun has passed over the whole ecliptic and it is again the Vernal Equinox.

Sun's R. A. = 360° or 24 hours, and its **Decl.** = 0.

If we require the sun's R. A. at other dates we can obtain it exactly from the Nautical Almanac; or, knowing the sun's R. A. at the nearest equinox or solstice, we may obtain its R. A. approximately at other dates by adding 1° or 4 min. for every day later. Thus January 1 is ten days later than December 22 when its R. A. is 270° or 18 hours. We must therefore add 10° or 40 m. to the R. A. of December 22. Hence on January 1 the sun's R. A. = 280°, or 18 hours 40 m.

When we learn that celestial latitude and celestial longitude are measured with reference to the plane of the ecliptic and not the plane of the equator, we can see that the sun's latitude is always zero, as it is always on the ecliptic, and that the sun's longitude increases from zero at the first point of Aries up to 90° on June 21, to 180° on September 23, to 270° on December 22, and to 360° on March 21, when it is at the first point of Aries again.

283. **How to determine the Solstices, the Equinoxes, and the Obliquity of the Ecliptic.**—We will now explain a simple

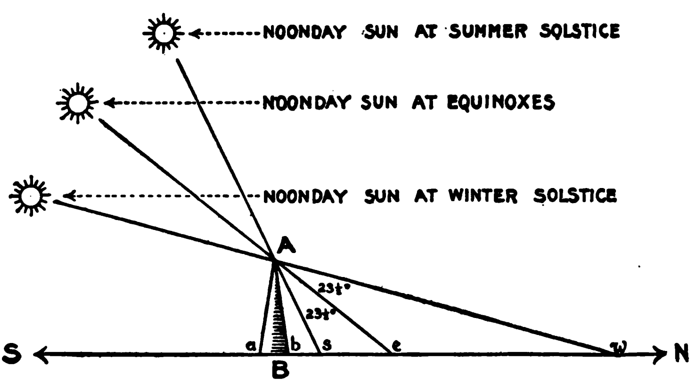


FIG. 260.—Illustrating how the sun's varying declination, the obliquity of the ecliptic, and the date of the equinoxes and solstices may be determined. *bs*, *be*, and *bw* show the relative lengths of the noonday shadow of the gnomon at the times indicated.

method of finding these dates and this angle. Fix a vertical rod or pillar, sometimes called a *gnomon*, on a horizontal surface and observe the noonday shadow cast by the sun. The day on which the shortest shadow is thrown at noon will be the

te of the summer solstice; the day on which the longest adow is thrown at noon will be the date of the winter solstice. he solstices may also be determined by finding the day on hich the sun rises and sets furthest from the east and west oints of the horizon. At the summer solstice it rises and sets irthest to the north; at the winter solstice it rises and sets earest to the south.

We may find the equinoxes or dates on which the sun's aily motion is on the equator by determining the day on hich the sun rises due east and sets due west, for the celestial quator cuts the horizon at these two points. A line at right ngles to the meridian line runs due east and west, and at each quinox the shadow of a vertical rod cast by the rising sun will e in the same straight line as that cast by the setting sun.

From the observations with the gnomon we may learn that le sun's declination or distance from the equator is 23½° N. at le summer solstice, and 23½° S. at the winter solstice. This therefore the angle between the plane of the ecliptic and the lane of the equator, and this angle of 23½° is the Obliquity f the Ecliptic. (See Fig. 260, where the opposite angles are qual.)

The length of the year may be approximately found by nding with the gnomon the interval between one summer olstice and the next, or one winter solstice and the next; that , by observing the times when the noonday shadow of the iomon is longest or shortest.

284. **The Sun's Diurnal Path at Different Latitudes and easons.**—We have learnt that the sun's position among the ars is not fixed, but that in his progress along the ecliptic he ot only changes his right ascension, or distance from the first oint of Aries, but his declination or distance from the equator changing from day to day, varying from 23½° N. to 23½° S., id back again in a year. This change of declination is the ason why the apparent daily path of the sun differs from day day during the year. Indeed, the change is gradual through- it each day, but it will be sufficient for our purpose to assume at the sun keeps the declination that he has at sunrise iroughout that day.

Let us now consider the daily motion of the sun on the celestial sphere in a somewhat similar manner to that in which we considered the daily motion of the stars in par. 272. There is this difference, however, to note between the sun and the stars. Each star describes its own daily path at various latitudes without any change throughout the year, the path depending on its distance from the equator. The sun's path changes during the year, so that at one time its path is like that of a star on the equator, at another period like that of a star above the equator (but never more than $23\frac{1}{2}°$ N.), and during another part of the year like that of a star south of the equator.

Take first the case of an observer at the equator, where the celestial poles are on the horizon, and where the equinoctial or celestial equator passes through the zenith. On March 21, when the sun is at the first point of Aries in his yearly circuit of the heavens, and when his declination is 0° (Fig. 259), he will rise at the east point of the horizon E, and set at the west, W, describing the equatorial arc EQW (Fig. 261). From March 21 to June 21 the sun is daily increasing its distance north of the celestial equator, so that it rises north of E and sets north of W. On June 21, the summer solstice (Fig. 259), the sun is $23\frac{1}{2}°$ north of the equinoctial, and its path on that day is represented by the arc *eUw*, half of which is above the horizon and half below. After June 21 the sun's northern declination decreases, and he is back again on the equator at the autumnal equinox, September 23 (Fig. 259). After September 23 the sun passes south of the equator, his diurnal

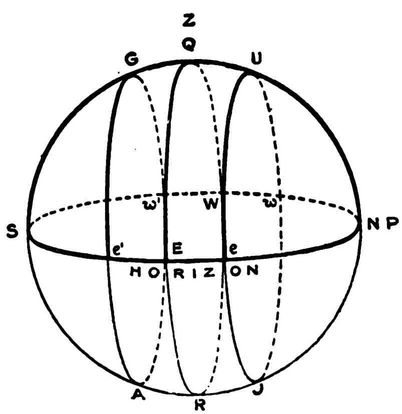


FIG. 261.—Figure illustrating the daily path of the sun at the equinoxes and solstices, to an observer at the equator.

circle appears to get smaller, and he rises south of E and sets south of W. On December 22, the winter solstice (Fig. 259), the sun's declination is $23\frac{1}{2}°$ S., and his daily path is represented by the circle AG, half of which, $e'Gw'$, is above the horizon. After December 22 the south declination of the sun decreases as he moves along the ecliptic to the first point of Aries (Fig. 259), a position he again reaches on March 21. Thus it is seen that at the equator the sun's daily path is always bisected by the horizon, and that day and night are always equal, though the amplitude of his rising and setting points varies from 0° to $23\frac{1}{2}°$ on each side. On March 21 the observer at the equator notes the sun passing through the zenith at noon; for six months it then transits the meridian north of the zenith; on September 23 it again passes through the zenith at noon; during the next six months it transits south of the zenith.

A little consideration will show that as we pass northwards from the equator, the daily path of the sun is not always half above and half below the horizon. From March 21, on which date the sun is on the equator, to June 21, the days increase and the nights decrease in length; from June 21 to September 23, the daily paths change back to the equator, and the length of the day returns to twelve hours. From September 23 to December 22, the days shorten as the sun passes south of the equator, but from December 22 the days again lengthen. As long, however, as we remain in the torrid zone, it will be found that the sun passes through the zenith twice a year.

Consider now an observer just outside the torrid zone, say in latitude 27° N. As before, on March 21 the sun's daily path is on the equator, and he rises in the east and sets in the west, day and night being each twelve hours. But from March 21 to June 21, as the sun's declination increases, more and more of his daily journey is above the horizon, and the day lengthens, his amplitude and noonday altitude daily increase, until at the summer solstice his path above the horizon is represented by the arc eUw in Fig. 262. It is now the longest day, and the arc SU gives the greatest noonday altitude for an observer at this position. After June 21 the sun gradually returns to the equator, when day and night are again equal.

From September 23 to December 22 the sun passes below the equator, the days get shorter than the nights, and the diurnal path above the horizon changes from EQW to *e'Gw'*. On December 22 the day is shortest, and the sun's meridian altitude SG is least. After this date the days again lengthen as the sun returns to the equator, and his daily path above the horizon again increases.

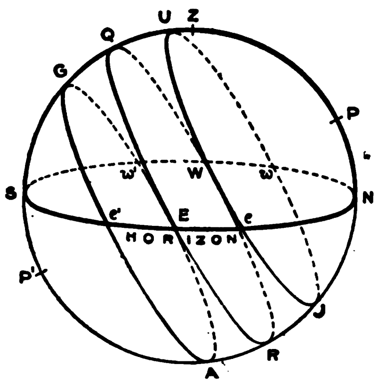


FIG. 262.—Diagram showing the daily path of the sun at the equinoxes and solstices, to an observer about lat. 27° N.

As we pass into higher latitudes than that just described, the variations in the length of day and night are of a similar character to those just described, but more marked. Part of Fig. 228 may be taken to represent the daily paths of the sun at London at the equinoxes and solstices, EMW being the path above the horizon when the sun is on the equator; *emw*, the path above the horizon when the sun has its greatest northern declination at the summer solstice; and *fnv*, the path above the horizon at the winter solstice.

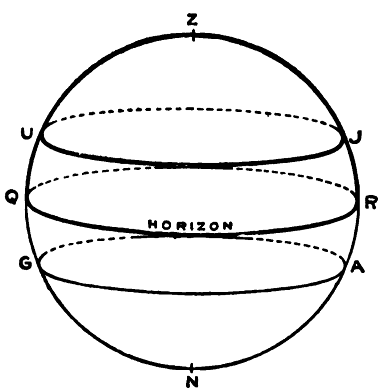


FIG. 263.—Diagram showing the daily path of the sun at the equinoxes and solstices, to an observer at the pole.

As we get nearer the poles the sun's daily path becomes more and more parallel to the horizon, until at the pole itself, where the equator coincides with the horizon, the sun's daily path on March 21 is on the horizon. From

March 21 to June 21 an observer at the pole would see the whole of the sun's diurnal circle as he passed from the south at noon to the north at midnight, and then back again to the south on the following noon. These daily journeys would be performed on circles parallel to the horizon, the daily parallels being more and more above the horizon until a distance of $23\frac{1}{2}°$ from the equator was reached, when the path is represented by JU in Fig. 263. The sun would then turn back and gradually approach the equator again during the next three months of daylight. After September 23 the sun would sink below the equator and horizon, and there would be darkness for six months.

We thus see how the annual variations in the sun's declination cause the varying lengths of day and night, cause his diurnal path and meridian altitude to change, and thus produce in our latitude the change from the small arch of low altitude seen at midwinter to the large arch of high altitude seen at midsummer (astronomically, midwinter is the beginning of the season called winter, December 22; midsummer is the beginning of the season called summer, June 21). (See par. 287.)

285. **Effect of the Earth's Annual Motion round the Sun.**—*Variations in length of Day and Night.*—We have in the preced-

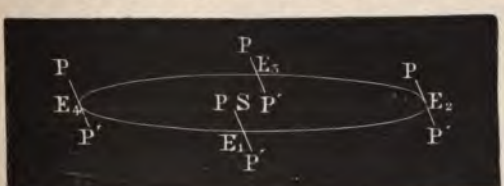


FIG. 264.—Showing how the earth's axis keeps its direction unchanged while the earth circles round the sun.

ing paragraph shown that the varying height of the midday sun causes the changes in its amplitude, and the varying length of day and night by speaking as if the sun moved round the earth in a year. We will now explain these phenomena by speaking of the earth's real annual motion round the sun at rest, and show that these phenomena are the result of the earth's revolution combined with the constant inclination of its axis at a

certain angle. During the earth's annual revolution round the sun the earth's axis remains constantly parallel, "for the mechanical reason that a spinning body maintains the direction of its axis invariable unless disturbed by extraneous force." That this is so is also evident from the fact that in all parts of its orbit the earth's axis points in the same direction, that is, to the celestial pole, and only parallel lines seem to meet at a point in vast distance. (A small periodic change in the direction of the earth's axis due to the action of extraneous force will afterwards be explained, but no account of this need be taken here.)

We have learnt that the plane of the earth's equator is inclined to the plane of the ecliptic at an angle of $23\frac{1}{2}°$, and as the earth's axis is perpendicular to the equatorial plane, it must be inclined from the perpendicular to the ecliptic plane at an

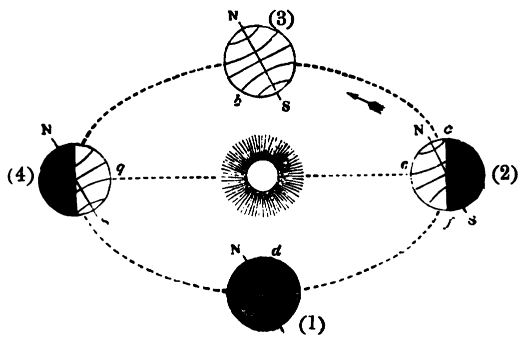


FIG. 265.—Earth's orbit, with earth at equinoxes and solstices. The four seasons.

angle of $23\frac{1}{2}°$. In other words, the earth's axis is inclined at an angle of $66\frac{1}{2}°$ ($90° - 23\frac{1}{2}°$) to the plane of the ecliptic itself. It follows, therefore, from the inclination of the earth's axis and its constant parallelism, that at certain parts of the earth's orbit round the sun one end of the axis is so disposed that it leans towards the sun, and in other parts of the orbit the same end leans away from the sun. At two positions of the orbit the axis is presented exactly sidewise to the sun, so that neither pole then inclines towards or from the sun. These facts are illustrated in Fig. 265, which the pupil must learn to reproduce, keeping the axis in each position of the earth parallel.

At any position of the earth in its orbit, a line joining the centres of the sun and earth fixes the place on the earth's surface which has the sun directly overhead or in the zenith. At the positions (1) and (3) the boundary between light and darkness runs exactly along a meridian of the earth and from pole to pole, so that as the earth rotates on its axis in these positions, day and night are then equal in all parts of the globe. The earth is in position (1) at the vernal equinox, and in position (3) at the autumnal equinox. At intermediate positions the inclination of the earth's axis to the plane of the ecliptic causes all the parallels of latitude on the earth, except the equator, to be cut equally by the boundary-line of light and darkness, and day and night are consequently unequal, the day being longer than the night in the Northern Hemisphere when it is shorter in the Southern Hemisphere, and *vice versâ*. Position (2) is the summer solstice, when the sun is vertical to places $23\frac{1}{2}^\circ$ north of the equator, when the north end of the axis is most inclined to the sun, and when the day is longest in the Northern Hemisphere, and shortest in the Southern. Further, it is plain that at the summer solstice the nearer we approach the north pole, the larger will be the portion of the parallel of latitude remaining in the light, as the earth rotates, and the longer the days; while the nearer we approach the south pole, the less will be the portion of a parallel in the light, and the shorter the days. In fact, within the Arctic Circle at the summer solstice an observer is never carried out of light by the earth's rotation, and he sees the *midnight sun* due north. Within the Antarctic Circle an observer remains in darkness while the earth rotates. From position (2) there is a gradual change to position (3), after which the sun descends below the equator until in position (4), the winter solstice, it is vertical over places $23\frac{1}{2}^\circ$ S. Here we have the exact opposite state of affairs, and we see why we have the short winter days and the long summer days in the British Isles and other places north of the equator.

These considerations again help us to see how the series of changes each year in the sun's declination or distance from the equator are brought about by the annual revolution of the earth combined with the inclination of the earth's axis to the

ecliptic plane, *i.e.* with the inclination of the plane of the equator to the plane of the ecliptic. And the annual changes of the sun's declination causes the variations of the sun's *amplitude* or distance of rising and setting from the east and west points throughout the year; for the further a body is north of the equator to an observer in the Northern Hemisphere, the greater is the portion of its daily circle of rotation above the horizon, and the further does it rise north of east and set north of west; while the further the body is south of the equator, the shorter is it above the horizon, and the further does it rise south of east and set south of west. At the equinoxes the sun's amplitude is 0° in all parts; at the solstices the sun has its maximum amplitude, but this varies in different parts of the earth, increasing with the latitude. The greatest amplitude at the solstices in latitude 50° (London in $51\frac{1}{2}^{\circ}$ N.) is $38\frac{1}{2}^{\circ}$.

So important is the proper understanding of the variation in the length of day and night at all places north and south of the equator (at the equator day and night are always of 12 hours each, as this parallel is always equally divided by the line of light and darkness), that we will further consider the four chief positions of the earth in its orbit. The orbit is, of course, in the plane of the ecliptic. NS in each case represents the axis of the earth.

Let us first consider the position (2) of Fig. 265, where N, the north pole, is towards the sun, and for this purpose we use a

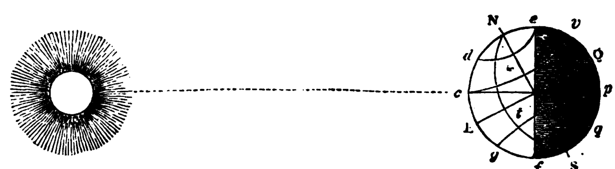


FIG. 266.—Northern summer and southern winter.

separate figure. In this figure, *ef* represents a plane perpendicular to the line joining the centres of the sun and earth. All that part of the earth on the side of *ef* nearer the sun is illuminated and has daylight; all on the further side has darkness and night. A plane perpendicular to the axis is the plane of the equator EQ.

The circle *ed* described on the earth passing through *e*, the extremity of the shadow, is called the Arctic Circle. We see that a place within the Arctic Circle never loses sight of the sun, never entering the shaded half, during a rotation about the axis NS, so long as the earth and the sun are in the positions indicated by the figure. The corresponding circle *fq* in the Southern Hemisphere is such that all places within it never see the sun during a rotation, the conditions being the same. This circle is the *Antarctic Circle.* The circle *cv*, passing through the point *c* directly under the sun, is called the *Tropic of Cancer.* The corresponding circle *gp* in the Southern Hemisphere is the *Tropic of Capricorn.* (See note, par. 217.) We have considered the effect of rotation at places included in the Arctic and Antarctic Circles. Between the Arctic Circle and the equator all places will evidently see the sun for more than half a rotation—*i.e.* have a longer day than night; for more than one-half of each parallel in the Northern Hemisphere is in the light. Between the Antarctic Circle and the equator the reverse will be the case, night being longer than day. The sun will during the course of the day pass overhead to all places on the circle *c v*. All this, we must remember, is while the earth is in the position when the north pole is most inclined towards the sun.

The next figure (267) shows the earth at the opposite side of the orbit, where the two hemispheres are just reversed in all

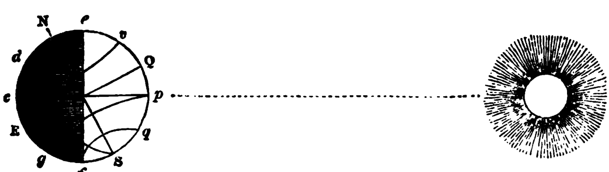


FIG. 267.—Northern winter and southern summer.

respects so far as light from the sun is concerned. Thus within the Arctic Circle there is no sunlight during the rotation round the axis; within the Antarctic Circle the sun is not lost sight of during the rotation. Between the equator and the Arctic Circle night is longer than day, and between the equator and the Antarctic Circle day is longer than night.

At either of the intermediate positions the appearances are the same. In these two positions the earth's axis is perpendicular to the line joining the centre of the earth and sun, as we see by a figure (268); and here we see that day and night are of the same length at all parts of the earth. These positions are called the *equinoxes*, because day and night are of equal length. The first two positions discussed are called the *solstices*.[1] From solstice to equinox the appearances above described change gradually, and so from the equinox round to the other solstice. Thus in the Northern Hemisphere at the first solstice the sun at midday is high in the heavens, and on each succeeding midday gets lower and lower; at the same time the day shortens and the night lengthens till the equinox, when they are equal in length. After the equinox the sun is

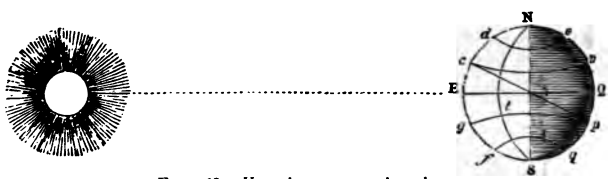


FIG. 268.—Vernal or autumnal equinox.

still lower at midday, and now the nights are longer than the days, and the difference increases till the other solstice is reached. Then the midday sun is at its lowest in the heavens, and on two successive days seems to occupy the same place—to stand still, as it were, and hence the name solstice. After this the changes are all gone through back again till the other solstice is reached, and then we say one year is completed.

We notice, further, that all places within the Arctic Circle have at least one day in which the sun never sets, and one in which it never rises. The poles themselves see the sun for six months and lose it for six months. Within the two tropics every place has the sun overhead, or in the zenith, at least twice a year. This occurs on two successive days at the tropics

[1] Solstices (Lat. *sol*, the sun, and *stare*, to stand), the times at which the sun reaches its greatest distance from the equator, because it then appears to stand still before the direction of its motion is changed towards the equator again.

themselves, the sun rising day after day higher and higher, till it becomes vertical at midday, and then it seems to "turn back" —hence the name tropic. Outside the two tropics, and below the Arctic and Antarctic Circles, we have two zones which have appearances lying between the two described, for they never have a vertical sun, nor a day in which the sun fails to rise or set.

The following table shows the longest duration of sunset— *i.e.* the longest day at different latitudes :—

Latitude.		Latitude.	
0° (Equator)	$12^h\ 0^m$	60°	$18^h\ 30^m$
10°	$12^h\ 35^m$	66° 33′ (Arctic Circle)	$24^h\ 0^m$
20°	$13^h\ 13^m$	70°	2 months
30°	$13^h\ 56^m$	80°	4½ months
40°	$14^h\ 51^m$	90° (Pole)	6 months
50°	$16^h\ 9^m$		

We add a diagram to illustrate these different lengths of the longest day at every 10° of latitude in the Northern Hemisphere

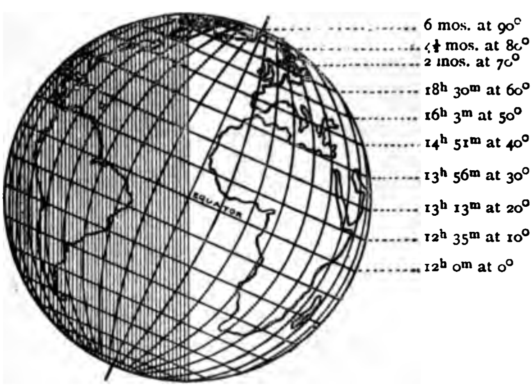


FIG. 269.

when the north end of the earth's axis is most inclined to the sun. The length of the longest night in winter is the same as that of the longest day in summer.

A simple way of illustrating the height of the midday sun at different parts of the year is shown in Figs. 275, 276. A line drawn *from the centre* of the earth through the situation of any

particular place passes to the zenith of that place, and a line from the centre of the earth to the sun will show thus the angle separating the sun from the zenith, *i.e.* the zenith distance. The zenith distance of the sun subtracted from 90° gives its altitude. The less the zenith distance, therefore, the greater is the altitude. In the figures, the letter L represents the latitude of London, and Z indicates its zenith.

286. **Distribution of Light and Heat on the Earth.**—That half of the earth's surface which is turned towards the sun receives light and heat from it ; the other half is in darkness.

The light, and especially the heat, derived from the sun at any place, are greatest when the sun is highest in the heavens, and can therefore send its rays more nearly perpendicular to the ground. There are two reasons for this :—

(1) When the sun is highest the rays from it pass through less of the earth's atmosphere, and so less heat is absorbed by that atmosphere before they reach the ground.

(2) When the sun is higher the number of rays received by any particular piece of ground is greater than when the sun is lower, *i.e.* the quantity of heat received by a square yard of ground increases as the sun's altitude increases. This is the main reason for the increased heating power of more perpendicular rays.

By a figure in connection with par. 179 we have seen how both these reasons combine to cause an increase in the heating power of the sun's rays as we approach the equator. The reader should again consider the paragraph carefully (see also pars. 180 and 181). Fig. 194 is drawn for one of the equinoxes, and it is now easily seen how at the summer solstice, when the Northern Hemisphere is more inclined towards the sun than at an equinox, any area north of the equator will receive its supply of the sun's rays more perpendicularly than at an equinox. In winter the rays will fall more obliquely, and their strength will be weakened. Fig. 270 shows the different angles at which the sun's rays strike the earth on June 21 and December 22, and it also illustrates the unequal distribution of an equal band of rays, *ab*, at these two angles.

But there is still another cause that affects the temperature

of the various parts of the earth at different periods of the year, for it must be plain that the length of the day, or the

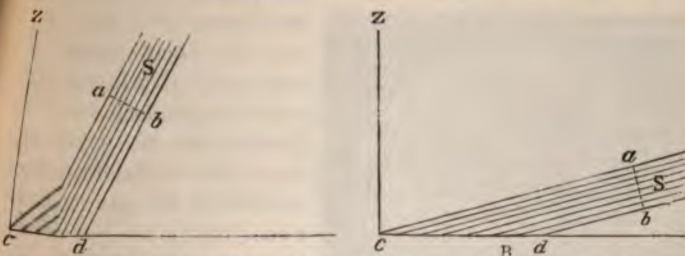


FIG. 270.—Showing the difference in the distribution of the sun's rays at London at midsummer (A) and at midwinter (B). The zenith distance of the sun at noon is about 28° at midsummer in the latitude of London, and about 75° at winter. Its altitude is therefore 90° − 28° = 62° in the former case, and 90° − 75° = 15° in the latter case.

time which the sun remains above the horizon, has great influence. While the sun is shining, those parts of the globe exposed to his rays are receiving heat; after the sun has set, these parts are losing heat, the heat passing away by radiation into space. Hence places are most heated when the days are longest. The more distant a place is from the equator the greater is the difference between the length of its days and nights, and the greater will be the variation of its temperature during the year. Although we receive most heat in 24 hours at the time of the summer solstice, this is not the hottest time of the year. The maximum temperature at any place usually occurs at the end of July, because during most of the summer the heat received from the sun during the day is in excess of that lost by radiation during the night, and so the

FIG. 271.

temperature goes on increasing until the loss by night is just equal to the gain by day. (So the greatest heat of any day is not until about two hours after noon, when the gain and loss each minute is balanced.) In autumn the loss by night begins to be greater than the gain by day. The minimum temperature of the year occurs when the gain by day again becomes equal to the loss by night, and this happens about the end of January.

FIG. 272.

Some of the facts set forth in this and the preceding paragraph are well shown in a different way in Figs. 271 to 274.

These figures show how the earth is presented to the sun at the four seasons, or four chief positions of its orbit. They are sun-views of the earth, such as an observer on the surface of the sun might obtain. At the vernal equinox sunlight reaches from pole to pole, and every place would be seen to pass straight across as the earth rotates from west to east, each place being twelve hours in sunlight and twelve hours in darkness.

FIG. 273.

Day and night are thus equal. As the earth moves on in its orbit round the sun in the direction of the large arrow passing through the earth and with its axis unchanged in

direction, a little consideration will show that the parts round the north pole will gradually come into greater view, while the parts round the south pole will pass out of view. When the earth has reached the position of the summer solstice at midsummer, we see that the aspect it presents to the observer on the sun is greatly changed. Places in the Northern Hemisphere remain in view more than twelve hours, for the rotating earth carries them round on a curved path, the curve being bent downwards as the equator and other circles of latitude are seen to be. England is seen to be well down towards the centre of the illuminated half of the earth, and the sun's rays are therefore received more vertically than at the vernal equinox, and it appears larger to the supposed spectator

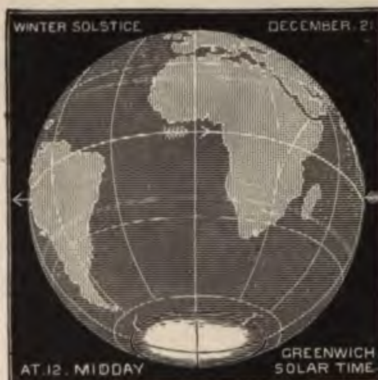
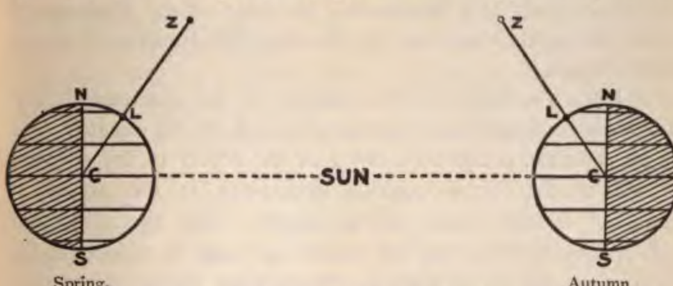


FIG. 274.



Spring. Autumn

FIG. 275.—Diagram showing the equality of the sun's zenith-distance at the two equinoxes. Angle ZCS (sun) = zenith distance.

on the sun. Places within the Arctic Circle go round and round as the earth rotates without passing out of sunlight, while places near the south pole are never brought into light, so that the sun never sets in arctic regions, and never rises in

the antarctic regions. There is a "midnight sun" in the north part of the sky beyond latitude $66\frac{1}{2}°$ N. At the autumnal equinox matters are the same as when the earth was at the vernal equinox. At the winter solstice the region round the north pole is turned away from the sun, and the region round the south pole enjoys continuous sunlight. Places north of

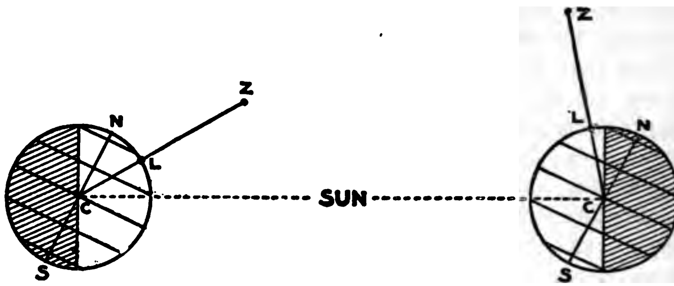


FIG. 276.—Diagram showing the difference between the sun's zenith-distance at the two solstices at the latitude of London. Angle ZCS subtracted from 90° gives the altitude.

the equator follow the paths indicated, and are less than twelve hours in sunlight, while places south of the equator are more than twelve hours in sunlight. England now receives the sun's rays so obliquely and lies so near the edge of the illuminated half of the earth, that it cannot be properly represented on so small a figure.

It will be noticed that the middle of the illuminated half of the earth is alternately north and south of the equator, and the sun at noon is therefore twice in the zenith at the equator —once at the vernal equinox and once at the autumnal equinox. Between the vernal equinox and the autumnal equinox he is twice in the zenith at noon to places as far north as the Tropic of Cancer. Between the autumnal equinox and the vernal equinox he is twice overhead at noon to places south of the equator as far as the Tropic of Capricorn. In other latitudes he is never seen in the zenith.

287. **The Seasons.**—Remembering how the effect of the sun's heat on any part of the earth's surface depends on its *height* in the heavens, and the length of time it shines, and

remembering also the explanation of the different lengths of night and day, we shall easily explain the succession of the seasons.

Considering either hemisphere, say the northern, we take the position of the earth at that solstice when the north pole is most turned towards the sun. There are now long days and short nights, and the sun is higher in the heavens at midday, and thus for both reasons it is warm in this hemisphere; in fact, it is midsummer. Summer lasts until the earth reaches the equinox, nights and days being now equal, and autumn begins. Autumn lasts till the other solstice is reached. Then it is midwinter, being cold, for nights are at their longest, days being shortest, and the midday sun is at its lowest. Winter lasts till the next equinox, and then it is spring. Spring lasts from this equinox to the summer solstice. As the Northern and Southern Hemispheres are reciprocal in the lengths of their days and nights, we see that the seasons will be reciprocal. Thus when it is summer in the Northern Hemisphere it is winter in the Southern. When spring in the Northern it is autumn in the Southern, and *vice versâ.*

We may notice that between the two tropics the midday sun is always very high in the heavens, and the nights are never much longer than twelve hours; thus it is always hot there—a perpetual summer—and this zone or belt of land is therefore called the *Torrid Zone.* At places included in the Arctic and Antarctic Circles the sun never rises high, and though this in summer is somewhat compensated for by the long days, still it is always cold there—a perpetual winter—and hence the zones are called respectively the *North* and *South Frigid Zones.* Between the North Frigid Zone and Torrid Zone we have the *North Temperate Zone*, and between the South Frigid Zone and Torrid Zone we have the *South Temperate Zone.* In these Temperate Zones the winters are neither very cold nor the summers very hot; hence their names. It is in these zones that the four seasonal changes are most marked.

Fig. 277 shows different positions of the earth in its orbit *as seen from above* the ecliptic plane, thus illustrating the

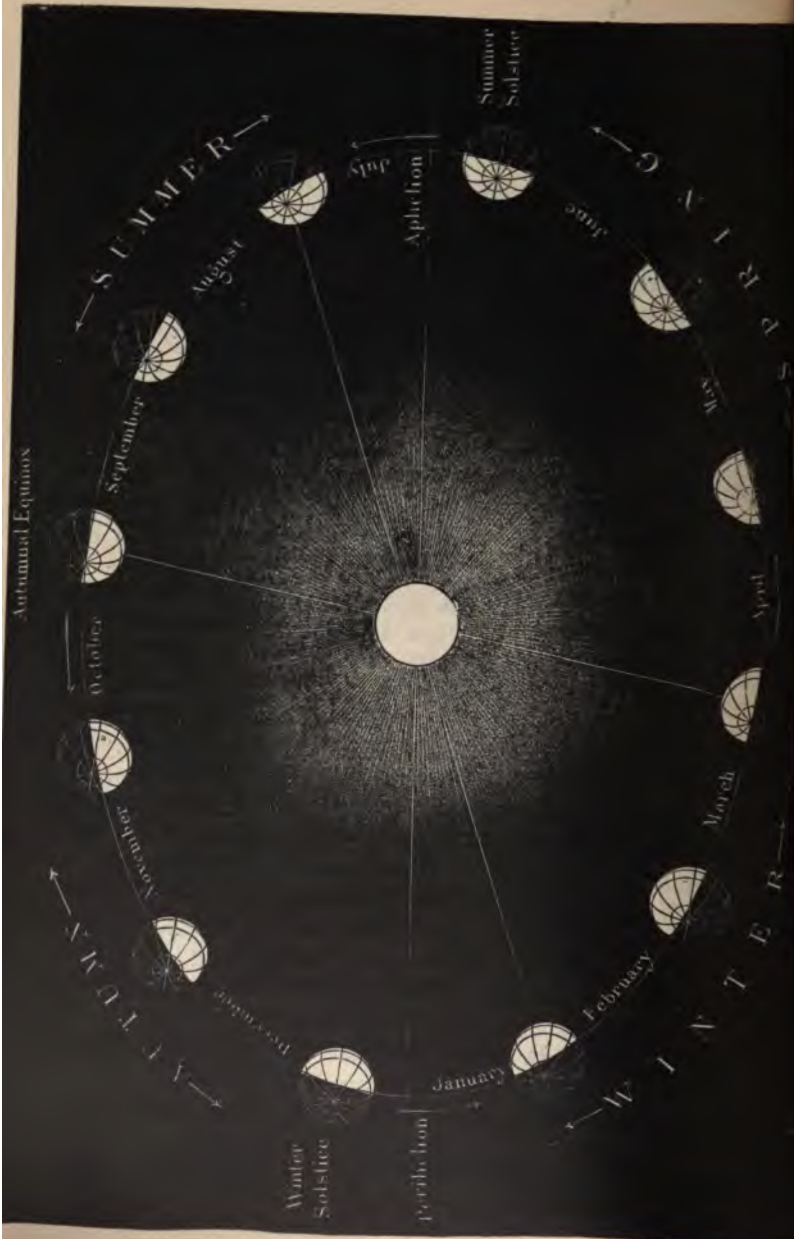

SUMMER
SPRING
WINTER
AUTUMN
Summer Solstice
Aphelion
July
June
May
April
March
February
January
Perihelion
Winter Solstice
December
November
October
Autumnal Equinox
September
August

FIG. 277.

change of seasons throughout a year. The figure is drawn for the Northern Hemisphere, the figure for the Southern being similar, the seasons being reciprocal to the former. It will be instructive for the pupil to begin at the bottom of the figure, where the earth is seen in the position it occupies about March 21 (when both poles are equally distant from the sun), and to follow the earth through its monthly changes, noticing the boundary of the enlightened hemisphere in the successive periods as the earth revolves on its axis, and at the same time makes its yearly revolution round the sun.

It will be noticed that the winter solstice occurs very near the perihelion, and the summer solstice near the aphelion; thus, in the winter of the Northern Hemisphere the earth is nearest the sun, and in summer furthest from the sun. For the Southern Hemisphere the earth then is nearest in summer and furthest away in winter. As it is warmer the nearer we are to the sun, the southern summer will be slightly hotter than the northern one, and the southern winter slightly colder than the northern one. This difference of distance is small, and the resulting difference in climate is small, and may, moreover, be masked by local causes, as the prevalence of hot or cold winds and ocean currents. The different months are marked in the figure, and we see winter lasts during January, February, March; spring during April, May, June; summer during July, August, September; and autumn during October, November, December. The exact durations of the seasons we get by knowing the dates of the equinoxes and solstices.

(We remember that perihelion occurs January 1, and aphelion on July 1.)

The Vernal or Spring Equinox is on March 21, and Spring begins.
The Summer Solstice is on June 22, and Summer begins.
The Autumnal Equinox is on September 23, and Autumn begins.
The Winter Solstice is on December 22, and Winter begins.

Finding the intervals between these dates, we shall learn that the seasons are of unequal length. Winter is about 4½ days shorter than summer in our hemisphere. We say "about," because to be quite accurate we should give the exact time on the above dates when each season begins, for spring begins at

the moment the sun reaches the vernal equinox on March 21; summer, the moment the sun reaches the summer solstice on June 21, and so on. The four seasons are, in fact, the periods into which the year is divided by the equinoxes and solstices. Their lengths at present are to the fraction of an hour—

Winter.	Autumn.	Spring.	Summer.
89 d. 0½ h.	89 d. 18½ h.	92 d. 20¾ h.	93 d. 14½ h.

Spring and summer together, when the sun is north of the equator, are thus about seven days longer than autumn and winter. What is the cause of this inequality in the length of the seasons?

Fig. 278 is a representation of the earth's orbit with the ellipse exaggerated. The two equinoctial and the two solstitial

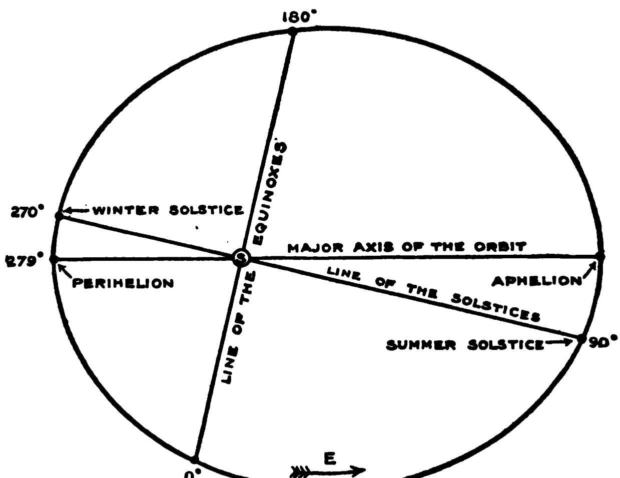


FIG. 278.—Illustrating the inequality in the length of the seasons. From the vernal equinox, 0°, to the summer solstice, 90°, it is spring; from the summer solstice, 90°, to the autumnal equinox, 180°, it is summer; from the autumnal equinox to the winter solstice, it is autumn; from the winter solstice, 270°, to the vernal equinox, it is winter.

points divide the orbit or ecliptic into four equal portions 90° apart, but, owing to the varying speed of the earth in its orbit (travelling more quickly the nearer it is to the sun, and the more slowly the more distant it is), these equal portions are not described in equal times. The line through the sun in one

focus of the ellipse from the spring equinox, 0°, to the autumnal equinox, 180°, and the line at right angles joining the two solstices divide the area of the figure into four unequal quadrants, and the areas of the quadrants being unequal, Kepler's second law—that the radius vector or line joining the earth and sun sweeps over equal areas in equal times—shows that the times in which the sun describes them are unequal and proportional to the areas.

Summary of the Effects of the Rotation and Revolution of the Earth.

Rotation causes the risings and settings and daily apparent motions of the sun and stars, and thus causes day and night.

Revolution causes the sun to appear to move eastward amongst the stars through the twelve signs of the zodiac, and thus stars rise about four minutes earlier on successive nights. It also produces the yearly changes in the sun's Right Ascension.

Revolution combined with the inclination of the planes of the equator and ecliptic (*i.e.* the inclination of the earth's axis) causes the yearly variations in the sun's declination (*i.e.* the varying height of the midday sun), the difference in length of the days and nights, and thus causes the succession of the seasons.

Rotation gives us the length of the day; *revolution* gives us the length of the year.

Different Kinds of Year.—A year is the period of the earth's revolution about the sun from a certain position back again to the same.

The **Sidereal Year** is the time taken by the sun in completing a revolution from a given star or other fixed point to the same star again. Its length is 365·256 mean solar days. The sidereal year is the time of the true orbital revolution of the earth.

The **Tropical** or **Equinoctial Year** is the time which the sun takes to pass from vernal equinox to vernal equinox again. As the vernal equinox advances 50·2″ each year to meet the sun, the tropical year is about 20 minutes shorter than the sidereal year. Its length is 365·242 mean solar days.

For ordinary purposes a year containing a fraction of a day would be *inconvenient*, and so the *civil year*, or the year of the

calendar, is some whole number of days, generally 365 days, which is rather less than a tropical year. But we want the seasons, which are determined by the tropical year, to always occur at the same parts of the civil year, and therefore we try to bring these two years into agreement.

The difference amounts to nearly a quarter of a day, hence every four years we have a leap-year, containing 366 days, the ordinary years containing 365 days. But the difference is not quite a quarter of a day, and hence in 400 years we omit three of such leap-years, and make these ordinary years of 365 days. This makes the average length of the year almost exactly what it should be, viz. 365·2421 days. Therefore every year has 365 days, except every fourth year, which is such that its number is divisible by four, and this has 366 days, except again that those centuries which are not divisible by 400 have only 365 days. Thus 1884, 1864, 1840 were leap-years, and so were 1600, 1200, 800; but 1800, 1700 were not, and 1900 will not be a leap-year.

The **Anomalistic Year** has for its starting-point the perihelion of the earth's orbit, and is therefore the time between the two successive passages of the perihelion by the earth. As perihelion point moves eastward or backward each year about 11·25″, this year is nearly 5 minutes longer than the sidereal year. Its length is 365·259 mean solar days.

The relative magnitudes of the three kinds of astronomical year may be thus stated to the nearest second of mean solar time:—

Sidereal year	$= 360^\circ$	= 365 d. 6 h. 9 m. 9 s.
Tropical year	$= 360^\circ - 50{\cdot}2''$	= 365 d. 5 h. 48 m. 46 s.
Anomalistic year	$= 360^\circ + 11{\cdot}5''$	= 365 d. 6 h. 13 m. 48 s.

288. **Effects of a Change of Angle between the Equator and the Ecliptic.**—Any change of this angle means, of course, a change of inclination in the earth's axis. If the earth's axis had been perpendicular to the plane of its orbit, the plane of its equator would have coincided with the plane of the ecliptic, day and night would have been of equal length at every place throughout the year, and there would have been no *diversity of* seasons. (The axis of the planet Jupiter is almost

perpendicular to its orbit.) If the inclination of the earth's axis had been greater than it is, the sun would recede farther from the equator on the north side in summer, and farther on the south side in winter. A larger part of the earth would thus be in tropical regions and have the sun overhead twice a year, and a larger part would also be in arctic regions, with at least one day without any sunrise. Seasonal differences and changes in the length of the day would thus be increased. With an inclination of 45°, the tropical zones would extend 45° on each side of the equator, and the temperate zones would disappear, for the rest would be two arctic zones. Further increase of inclination would lead to an extension of the zones on each side of the equator where the sun would be overhead twice a year, and a further extension of the regions where the sun would remain above the horizon in summer and below the horizon in winter for one or more days. The great extremes of temperature in these latter regions would be very inimical to animal and vegetable life. Were the axis of the earth parallel to the plane of its orbit, the poles of the equator would be situated in the ecliptic; the seasonal changes would be extreme, every part being in turn tropical and arctic.

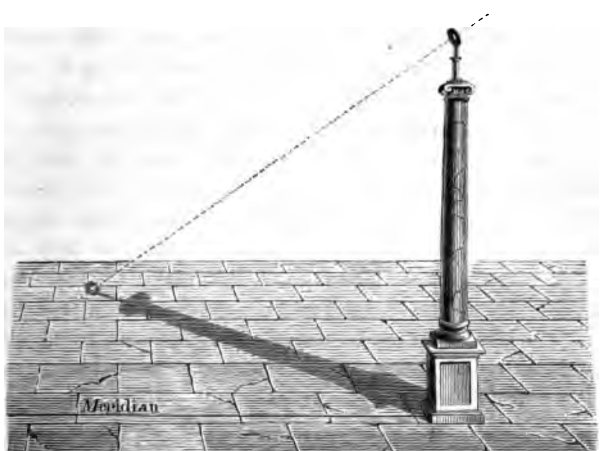


Fig. 279.—Egyptian obelisk used as a gnomon.

CHAPTER XXIII.

THE SUN, MOON, ECLIPSES, AND ASTRONOMICAL MEASUREMENTS.

289. **The Sun—Its Dimension, Density, and Attraction.**—The sun is an intensely hot self-luminous globe of enormous size, situated at a *mean* distance from the earth of about 92,800,000 miles. Knowing its distance, and measuring the angular diameter of its disc (par. 278), its real diameter is found by calculation to be 860,000 miles, or nearly 110 times that of the earth. Since the volumes of spheres are in proportion to the *cubes* of their diameters, the sun's *volume* = $(110)^3 \times$ vol. of earth; that is, 1,331,000 times the volume of the earth. This means that the volume of the sun is so great, that were the earth placed in the centre of the sun, with its satellite the moon revolving round it at a distance of 238,000 miles, still the earth and the orbit of the moon together would reach but little beyond half-way to the circumference of the sun. Yet though the *volume* of the sun is 1,330,000 times that of the earth, its *mass*, or the quantity of matter contained in it, is only 330,000 times that of the earth. In other words, while it would take 1,330,000 globes as large as the earth to make a globe as *large* as the sun, yet it would only take 330,000 to make one as *heavy* as the sun. From this it follows that its *density*, or quantity of matter per unit of space, is only about *one-quarter* of the earth's density, as we find on dividing its mass compared with the earth by its volume compared with the earth.[1] The force of gravity at the sun's surface is nearly twenty-eight times the

[1] The density of the earth compared with water—that is, its specific *gravity*—is 5·5; hence the specific gravity of the sun is only about 1·4.

force of gravity on the surface of the earth; and as the weight of a body is due to the force of gravity, a body at the surface of the sun would weigh twenty-eight times as much as upon the earth.

The physical condition of the sun is very different from that of the earth, though we know it is composed of very similar materials. The white-hot surface that we see, called the *photosphere*, is believed to be largely a shell of highly heated metallic vapours surrounding the unseen mass beneath. Dark spaces seen in the photosphere are known as *sun-spots*,

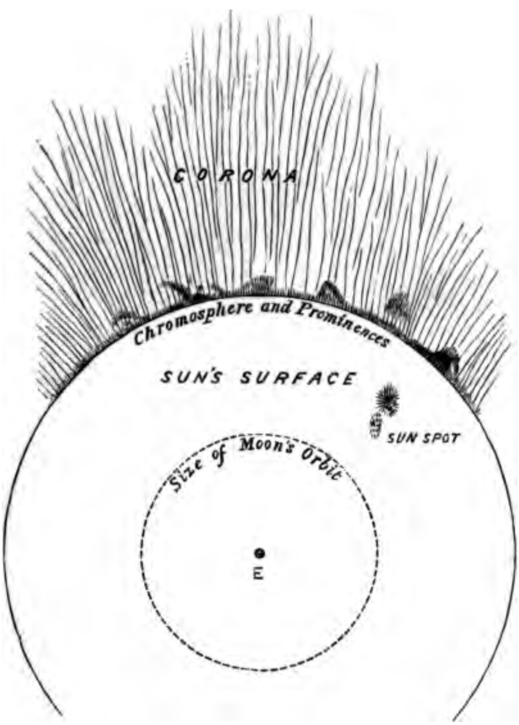


FIG. 280.—Comparative sizes of sun and earth.

and these are often surrounded by brighter patches, termed *faculæ*. Above the photosphere a shallow envelope of gases, rising here and there into huge prominences, and known as the *chromosphere*, is seen in red tints when the sun is totally eclipsed. Beyond the chromosphere, there is also seen, at the same time, a faint but far more extensive envelope called the *corona*.

The sun's rays supply light and heat not only to the earth, but also to

the other planets which revolve round it. Its attraction confines these planets in their orbits and controls their motions. Kepler's three laws of planetary motion have already been given (par. 277). Kepler derived these laws from observation only, but Newton first *explained* them by showing that they were the necessary consequences of the laws of motion and the law of universal gravitation. The centre of gravity of the *solar system* (as the sun with his attendant bodies is called) is the real point around which the planets revolve, but so enormous is the mass of the sun, that this point is situated not far from the sun's centre. (See par. 48.)

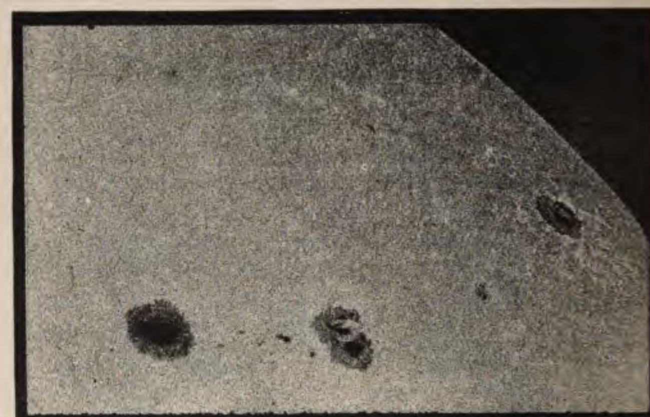


FIG. 281.—Part of sun's photosphere, with sun-spots and faculæ.

290. **The Moon.**—The moon is one of the secondary planets, or satellites, and it revolves round its primary the earth, while the latter is revolving round the sun. Its mean distance from the earth is only 239,000 miles. Though apparently as large as the sun owing to its nearness, its real diameter is only 2160 miles, and its volume, or bulk, only $\frac{1}{49}$ that of the earth. Its mass, or weight, is only $\frac{1}{80}$ that of the earth, and hence its density or compactness of matter is but a little more than $\frac{3}{5}$ that of the earth, and the force of gravity on its surface but $\frac{1}{6}$ that of the earth.

Besides its daily apparent motion from east to west, due to the daily rotation of the earth, it is easy to notice that it has an opposite motion, moving eastward among the fixed stars, *in consequence* of which it rises about 50 minutes later each *night*. A complete revolution of the moon round the heavens

from one fixed star to the same fixed star is called a *sidereal* revolution and occupies 27 d. 7 h. 43 m.

The moon requires a longer interval to go through a revolution with respect to the sun, as the sun also moves eastward among the stars, though at a slower rate. Hence the *synodic* month, or the time occupied by the moon in passing from the sun round to the sun again, is longer than the *sidereal* month by more than two days. The mean value of the synodic month is 29·53 days, and this is the ordinary *lunar* month. *Calendar* months consist of a whole number of days—28, 30, or 31 as the case may be. In a year there are twelve calendar months, but thirteen lunar months.

The moon's path among the stars is not situated in the same plane as the earth's path round the sun, for the moon's orbit is found to be inclined to the plane of the ecliptic at an angle of about 5°. The points at which the moon's orbit cuts the plane of the ecliptic are called the moon's *nodes* (see Fig. 226).

When the moon in her orbit lies between the sun and the earth, she is said to be in *conjunction* with the sun; when the earth is between the moon and the sun, the moon is said to be in *opposition* to the sun. At either of the two points midway from conjunction and opposition, *i.e.* 90° from conjunction or opposition, the moon is said to be in *quadrature*.

The moon is an opaque, cold globe, covered with mountains, extinct volcanoes, and plains. She has neither water nor atmosphere, and always presents the same surface to the earth in consequence of rotating on her axis in the same time as she revolves round the earth. Moonlight is only reflected sunlight, the illuminated hemisphere being always turned towards the sun. When we see the whole lit-up side of the moon, she appears circular, and we say the moon is full. But we cannot see the whole of the illuminated hemisphere from the earth at all times. The various shapes this illuminated hemisphere assumes in the course of her journey round the earth are called the *phases* of the moon. A figure will help us to understand these appearances, or *phases*, of the moon.

The figure represents the moon in eight different positions in her orbit round the earth, the sun being at an immense distance to the right. The line *m n* separates the illuminated half of the moon from the unilluminated half, and the line *a b* may be taken to separate the half of the moon turned towards the observer at E from that turned away from him.

At A the moon is in conjunction, being between the earth and the sun, and no portion of the illuminated half is visible. It is then said to be *new moon*.

At B, between four and five days afterwards, a small part of the lit-up

surface is seen, and this appears as a thin *crescent* in the sky just after sunset.[1]

At C the moon is in quadrature, at her *first quarter*, and one half the lit-up hemisphere is seen by the observer; so that the moon appears in the sky as a bright semicircle. It is *half-moon*.

At D more than half the lit-up hemisphere is seen, and the moon appears *gibbous* (Lat. *gibbus*, a hump) in the sky.

Before the end of 15 days the moon is in *opposition* to the sun at M, and the whole of the illuminated hemisphere is turned towards the observer, so that it is seen as a complete circular *disc* in the sky. It is now said to be *full moon*.

After full moon, the moon becomes gibbous again, F; in a few more days it is again half moon at the *third* or *last quarter*, G; and as it gets towards the sun, more and more of the dark side turns towards us, so that the crescent H grows narrower and narrower, until it disappears at new moon again.

It is worthy of note that the moon is higher in the heavens and longer above the horizon in the winter than in summer. This is owing to the plane of its orbit being at night high towards the south in winter and low in summer, as is the ecliptic.

The moon's orbit, like that of other planets, is elliptical, but irregular. When nearest to the earth, she is said to be in *perigee;* when at the greatest distance, in *apogee*.

291. **Eclipses, Lunar and Solar.**—Since light proceeds in straight lines, part of the space behind any opaque body is shut off from the light in front of it, and the space thus darkened is termed a shadow. Both the spherical earth and the moon cast conical shadows into the space behind opposite to the sun, and any body lit up by the sun entering one of these shadows becomes invisible, or is eclipsed.

An eclipse of the *moon* is caused whenever it passes into the shadow-cone cast by the earth. This can only happen with the moon full, *i.e.* in opposition; for at no other time is the earth between the sun and the moon. If the moon's orbit were in the same plane or level as the earth's orbit, a lunar eclipse (Lat. *luna*, the moon) would occur every month at full moon; but owing to the inclination of the planes of the two orbits (Fig. 144) being about 5°, the moon may be to the north of the ecliptic or below to the south of the ecliptic at the time of opposition, and then the earth's shadow-cone misses the moon. If the moon, however, is at or near one of her *nodes* when in opposition to the sun, it must pass more or less into the earth's shadow; for the centres of the sun, earth, and moon are then in, or nearly in, the same plane, and the earth's shadow always reaches far beyond the greatest distance of the moon. Thus the two conditions for a lunar eclipse are—

(1) The moon must be in opposition, *i.e.* full.

(2) The moon must be at, or near, one of her nodes.

Lunar eclipses are of two kinds—*total* when the whole surface of the moon passes into the earth's shadow, and *partial* when only a part of the moon's surface passes into shade.

Fig. 283 illustrates a total eclipse of the moon when she is in opposition at one of her nodes, and all three bodies are supposed to be in one and the same plane—the plane of the page. S represents the sun, E the earth, and *m* different positions of the moon in her orbit about the time of

[1] When the moon is a crescent a portion of the dark side is often faintly visible, owing to sunlight reflected upon it from the earth.

opposition. By drawing lines from *g* and *h*, the upper and lower edges or limbs of the sun, through *e* and *f*, the upper and lower points of the earth, and continuing these lines till they meet at *k*, we determine the dark cone-

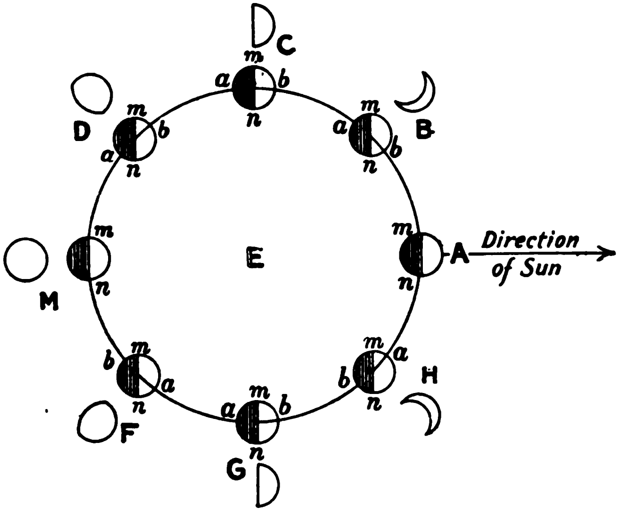


FIG. 282.—The figures upon the circle represent the chief positions of the moon in its orbit. The outside figures show the different phases.

shadow, or *umbra*, in which *all* the sun's light is cut off by the earth. By drawing the other lines, *hev* and *gfp*, from the upper and lower points of the sun through the opposite points of the earth, we find two

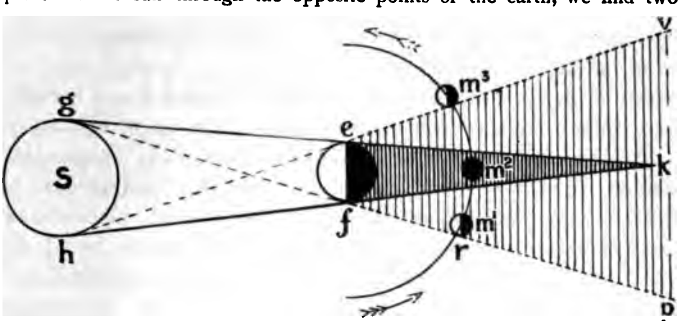


FIG. 283.—Eclipse of the moon when in the shadow of the earth.

spaces in which only a part of the sun's rays are cut off by the earth, and where, therefore, there is only a faint shadow called the *penumbra*.

A lunar eclipse begins with the first contact with the penumbra, though *there is but little darkening till* it enters the umbra. As the moon's eastern

limb enters the umbra, a part of the surface seems cut off, and in the case of a total eclipse the visible portion gets smaller and smaller till the whole disc passes into the shadow. A lunar eclipse will be total only when the moon is very near a node at the time of opposition, so that its course lies nearly through the centre of the umbra, and it may then last more than 1¾ hours. In many lunar eclipses the moon is so far from a node that it passes above or below the centre of the umbra, and a part is in the shadow and a part outside, the eclipse being partial.

Lunar eclipses are visible in the whole of that hemisphere of the earth which is turned towards the moon at the time, those inhabitants seeing the whole of the eclipse who have the moon above the horizon while the eclipse lasts.

In many cases of total eclipse the moon is still visible as a dull red or copper-coloured disc. This is owing to a small portion of sunlight being bent or refracted into the shadow by the earth's atmosphere.

An eclipse of the *sun* is seen whenever the moon's shadow-cone falls upon the earth. This can only happen at new moon, *i.e.* with the moon in conjunction. A *solar* eclipse, however, does not occur at every conjunction, on account of the inclination of the moon's orbit to the plane of the ecliptic. But if the moon should pass through either node at or near the time of conjunction, in certain parts of the earth the sun may be wholly or partially eclipsed. Thus the two conditions for a solar eclipse are—

(1) The moon must be in conjunction, *i.e.* new.

(2) The moon must be at or near one of her nodes.

Solar eclipses are of three kinds — *total*, *partial*, and *annular*.

The moon's umbra is only a little longer than her distance from the earth when the moon is nearest or in perigee, and the width of the shadow where it meets the earth seldom exceeds 150 miles. Hence only a small part of the earth can be in *total* darkness at any time. With the moon in apogee, the shadow does not reach the earth, only the central part of the sun can be eclipsed to observers in the shadow-cone produced; so that a ring of the sun is still visible round the central dark portion, and the eclipse is annular (Lat. *annulus*, a ring). We can illustrate the phenomena of solar eclipses by figures.

In Fig. 284 let S indicate the sun, E the earth, and M the moon at conjunction, with the moon at a node and in perigee. The dark shadow-cone, or umbra, determined by drawing the

tangent lines *gi* and *hk*, fall upon the earth's surface at *ab*. Within this space only is there a *total* eclipse of the sun, the eclipse beginning on the western limb of the sun. Between *a* and *c* there will be a partial eclipse of the sun, its lower portion being invisible; and between *b* and *d* there will also be a partial eclipse of the upper portion of the sun, both these portions being in penumbra. From *c* to *e* and from *d* to *f* no

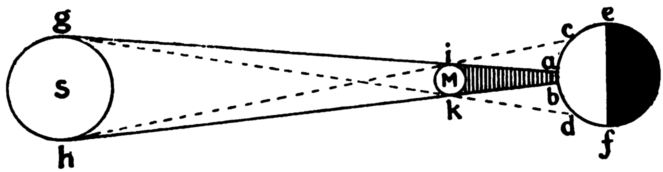


FIG. 284.—Eclipse of the sun (total in certain parts), the shadow of the moon falling on the earth.

eclipse is visible, nor is any eclipse seen in the shaded part of the earth where it is night.

As already remarked, a solar eclipse is total to but a small portion of the earth, the breadth of the shadow-cone covering but a small space (averaging from 130 to 160 miles), as illustrated by Figs. 284 and 285. The duration of totality at

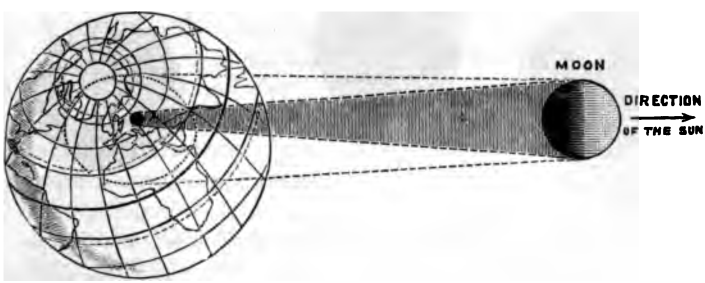


FIG. 285.—Lunar cone-shadow, showing where the solar eclipse is total.

any one place is small, varying from a few seconds to nearly 8 minutes, for the earth's rotation carries every place eastward much faster than the moon moves eastward, and thus the shadow-cone sweeps over a narrow belt of the earth until it passes from it.

To illustrate the conditions of an annular solar eclipse, consider Fig. 286, where *the moon at a node* and in conjunction is supposed to be in apogee

or at her greatest distance from the earth. In this case her apparent diameter is less than that of the sun, and the dark shadow falls short of the earth, *b*. Between the points *a* and *b*, where the shadow-cone produced meets the earth, the central parts of the sun are covered by the moon, and the outer portion of the sun is seen for a time as a ring or *annulus* of light. Here the eclipse is *annular* (Fig. 287). From *a* to *c* and from *b* to *d* a *partial* eclipse is visible (Fig. 288). Beyond *c* and *d* no eclipse takes place.

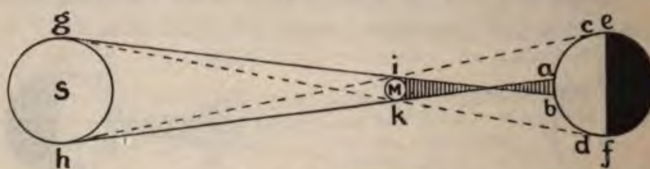


FIG. 286.—Annular eclipse of the sun, the shadow of the moon not reaching the earth.

There cannot be an annular eclipse of the moon, for the earth's shadow where it meets the moon is always greater in breadth than the diameter of the moon.

A total or annular eclipse of the sun is a rare occurrence at any particular place. No total eclipse of the sun will be visible in England until June 29, 1927, though one was visible in Norway on August 9, 1896.

FIG. 287.—Annular eclipse of the sun.

FIG. 288.—Partial eclipses of the sun.

Astronomers eagerly examine these phenomena in order to study the chromosphere and corona surrounding the sun's bright photosphere, for it is only during a total eclipse that these phenomena become visible.

Bearing in mind the conditions of lunar and solar eclipses, we can understand that, although the moon passes through a node about twenty-five times a year, it usually happens that she is not then in the same line as the earth and the sun, and that consequently eclipses do not happen as often. The greatest possible number that can happen in a year is seven—five solar and two lunar; the least possible number is two, both solar. But though solar eclipses are more numerous than lunar eclipses, it is not so with those visible at a given place. For a solar eclipse can only be seen by people who happen to be on the narrow track described by the moon's shadow across the earth, while a lunar eclipse is visible over the *whole* hemisphere that has the moon above the horizon during the eclipse.

292. **How to find the Size and Density of the Earth.**— As we may consider the earth a globe or sphere, every meridian circle is a circumference, and, like every other circle, contains 360 degrees. If, then, we find the length of one degree of a meridian, and multiply that length by 360, we get the earth's circumference. From the circumference we can obtain, by certain rules of mensuration, its other dimensions, that is, its *size*.

Very accurate measurements of the length of a degree have been made; but we will now indicate a simple though somewhat rough method. If we go exactly north along a meridian until the midday sun at the same time of the year is one degree lower in the sky, we have passed over one degree of a meridian of the earth. The distance thus traversed is found to be about 69 miles. Now, 69 miles $\times$ 360 = 24,840 miles, the length of the earth's circumference. Dividing this by $3\frac{1}{7}$, we get nearly 8000 miles for the diameter. Half the diameter is the radius, and from this we can obtain the area of the sphere, and the volume.

We may use a star in a similar way to the use of the sun. Measure the altitude of the pole-star or other star above the northern horizon, and then pass directly north on a meridian until the altitude of the star selected is one degree further from the horizon at the same time of the day. (Note that the altitude of the pole-star is always equal to the latitude of the place of observation.) The distance traversed gives the length of one degree of latitude on the earth's surface—69 miles, more exactly $69\frac{1}{10}$ miles. If we go directly south until the star is one degree nearer the horizon at the same time of the day, the same result is obtained.

The *mass* and *density* of the earth have been found by the Cavendish experiment, first performed in 1798. The force with which a large lead ball attracts a small ball, m, is measured by the aid of a torsion balance. The force with which the earth attracts the small ball m is the weight of m. Now, since the law of gravitation states that the force of gravitation of a body varies directly as its mass and inversely as the square of the distance, we get the following proportion:—

Attractive force of large ball on m : weight of m : : $\frac{m}{d^2} : \frac{M}{D^2}$ where m is the mass of the small ball, M the mass of the earth, d the distance between the centres of the two balls, and D the distance of the centre of the large ball from the centre of the earth, where the force of the earth's attraction may be regarded as collected. In this proportion the value of everything is known except M, and this can therefore be found from the proportion. As a result, the value of M is found to be about 6,000,000,000,000,000,000,000 tons (6 followed by 21 ciphers), which is the mass or weight of the earth. To find its density, or specific gravity, we must compare the weight of the earth with the weight of a globe of water the same size. Knowing that a cubic foot of water weighs 62½ lbs., we can find the weight of this globe of water. Its weight is 5½ times less than the weight of the earth. Hence the mean density of the earth, or its weight compared with an equal bulk of water,is 5½.

It is worthy of note that the rocks forming the earth's crust have only an average density of 2¾. A mean density of 5½, therefore, for the whole earth indicates that the interior of the earth has a much greater density than the outside.

293. **How to find the Sun's Distance from the Earth, the Dimensions and Density of the Sun.**—The planet Jupiter has five satellites, or moons, revolving round it, and these often suffer eclipse by passing into the planet's long conical shadow. Indeed, every satellite but one is eclipsed at every revolution, and the beginning (or end) of every eclipse occurs at nearly equal intervals of time, as the orbits of the moons are nearly circular, and lie in the plane of the planet's equator. The period of revolution and the interval between two eclipses of any satellite can thus be calculated and the times predicted. But Romer, a Danish astronomer, found that the times as first calculated and predicted were not exactly fulfilled at successive observations. Starting at the time of opposition, when the planet is nearest the earth (O, Fig. 289), the *observed* times fall more and more behind as the earth moves on in its orbit to Q^1. Near Q^1, supposing the planet to be still at J, Jupiter *is said to* be in quadrature, and the observed time is 499 seconds

behind. When the earth is at C, Jupiter is at his greatest distance and in conjunction, and the observed time near C is 998 seconds behind. Now, it is easy to see from the figure, that when the earth in its orbit is at Q^1, and the planet in quadrature, that the earth is further from Jupiter than when it is at O and Jupiter in opposition, by a radius of the earth's orbit. (At C the earth is two radii of its orbit further than when at O.) Why, then, is an eclipse-interval 499 seconds more when the earth is further from the planet by a radius of its orbit? Romer concluded that this was due to the greater

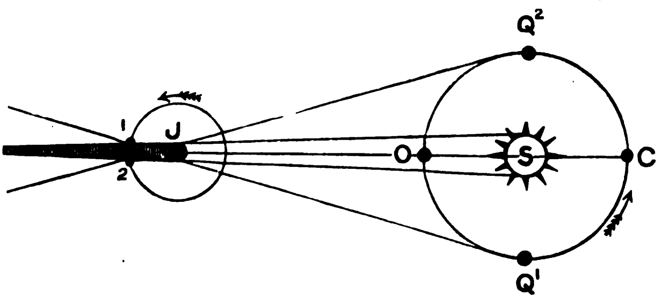


FIG. 289.—Illustrating eclipses of Jupiter's satellites.

distance that the light from the satellite had to travel. In other words, light requires 499 seconds to travel over the radius of the earth's orbit, *i.e.* the distance of the earth from the sun. If we can next learn the velocity of light, we shall be able to obtain the sun's distance. By experiments on the earth, light has been shown to travel with a velocity of 186,000 miles per second. We thus come to the simple question—If light travels 186,000 miles in one second, how far does it travel in 499 seconds? The answer is $186,000 \times 499 = 92,814,000$ miles, or nearly ninety-three million miles, and this is the distance of the earth from the sun.

When we know the distance of the earth from the sun, we can find the sun's diameter and other dimensions. For a halfpenny, which is just one inch in diameter, covers the sun's disc when held at about three yards from the eye. At twice the distance from the eye we should require a coin two inches in diameter, and so on. Now, the sun's distance may be taken at 93,000,000 miles, and this will be found to be 54,560,000,000 times greater than the distance of the halfpenny, and the diameter of the sun must *therefore be this number* of times greater than that of the halfpenny.

54,560,000,000 inches, or about 861,000 miles. From the diameter we can obtain the radius, the area of the surface, and the volume. The volume is found to be 1,300,000 times the volume of the earth. But the sun's mass, or quantity of matter, is only about 330,000 times that of the earth, and hence its density, compared with that of the earth, is $\frac{330,000}{1,300,000} = 0{\cdot}25$ nearly, that is about one-fourth of the density of the earth.

Now, the density, or specific gravity, of the earth, compared with water, is 5·5. One quarter of this gives nearly 1·4 for the mean density of the sun compared with water. No doubt this low density is due to the high temperature of the sun, which causes the materials of which it consists to be mainly in a state of vapour, or gas.

294. **Distance and Dimensions of the Moon.**—It is important to know that every triangle has three angles, and that the sum of these three angles is equal to 180°, *i.e.* to two right angles. If therefore the size of two angles be known, the size of the third angle can be readily found. Further, every triangle has three sides, and if of the six dimensions of a triangle, any three, one of these being a side, are known, the other dimensions can be computed. These facts may be illustrated by a simple piece of apparatus.

Experiment 109.—Take a rod or lath, AB, about a yard long, and place it on a table on which other objects are placed at a distance, as M, G, F, etc. From each end of the lath point another lath at the distant object M, and measure by graduated arcs the inclinations of the two pointers

FIG. 290. (*From Arnott's "Elements of Physics."*)

to the first lath. The length of the base AB being known, and the angles formed by the lines AM and BM, it is then easy to calculate the angle at M, and the length of the side AM or BM. In a similar way the distances AG, AF, etc., may be found. This illustrates the principles by which a surveyor or an astronomer calculates the distance of an inaccessible object.

The angle formed by an object when seen from different ends of a base line is called its *angle of parallax*. Parallax may also be described as the apparent displacement of an object when it is observed from different positions and referred to a background. This is further shown in Fig. 291.

Here AB is the base line, and the object X seen from A appears to be situated at x. Seen from B, however, it appears to be at x'. Angle AXB or its equals, xXx, or the subtended arc xx', is the parallax of the object X. A more distant object as P has a smaller apparent displacement when seen

from A and B, *i.e.* has a smaller parallax, and generally the more distant an object is the smaller is its parallax.

In a similar way astronomers find the distance of the moon and other heavenly bodies, the earth's diameter or a part of it being the base line. By the help of a figure and a little thought it will be seen that the nearer an object is to the zenith, the less will be its parallax, and *vice versâ*. An object will have the largest parallax when it is on the horizon (Fig. 292). The *equatorial horizontal parallax* of a heavenly body is the angle at the centre of the heavenly body subtended by a radius of the earth. In finding the distance of the moon, observations are made with suitable instruments at the end of a base line, so that the angle which a radius of the earth subtends at the centre of the moon can be calculated. The angle thus obtained is the moon's equatorial horizontal parallax. In Fig. 292 HME is the moon's horizontal parallax, or angle subtended at the centre of the moon by the earth's radius HE, when the moon is on the horizon. From the moon's horizontal parallax its distance can be found. For the other angles of the triangle HME are easily found, that at H being a right angle, since it is formed by the radius EH and the tangent-line MH, and the earth's radius EH has been before determined. Knowing one side and the angles of the triangle HME, the other sides HM or EM, the distance of the moon, can be calculated.

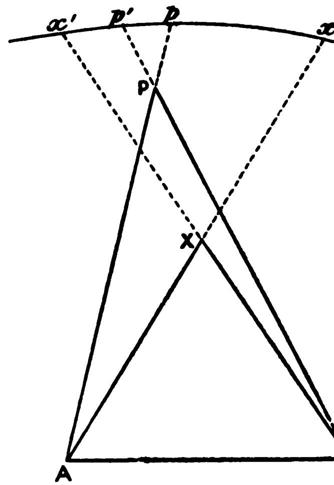


FIG. 291.—Illustrating parallax.

When we have found the moon's distance, we can find its real diameter and other dimensions, as in the case of the sun. Its apparent diameter is

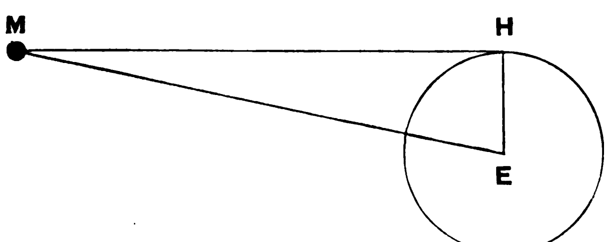


FIG. 292.—Moon's horizontal parallax.

nearly the same as that of the sun (about half a degree), and hence a halfpenny *one inch in diameter*, or a paper disc one inch in diameter, at a

distance of 9 feet just covers the full moon. Its mean distance being about 239,000 miles, it is about 137,000,000 times more distant than the halfpenny, and its diameter must therefore be the same number of times greater than the halfpenny—137,000,000 × 1 inch = 2160 miles nearly.

From this result its volume is found to be about $\frac{1}{49}$ of the earth's volume. The measurement of its mass gives about $\frac{1}{80}$ that of the earth's mass. As density is equal to mass divided by volume, its density is found to be a little more than $\frac{3}{5}$ that of the earth, or about 3·3 the density of water. The force of gravity on its surface is only $\frac{1}{6}$ that on the earth, so that a body would fall 2·6 feet in the first second instead of 16 feet as on the earth.

295. **The Celestial Globe.**—The celestial globe is a ball mounted in a framework, and upon it are drawn the circles of the celestial sphere and a map of the stars. A horizontal wooden ring going round the globe represents the rational horizon, a celestial object being visible if it be on that part of the globe above the plane of this horizon. The meridian is represented by a vertical brazen graduated circle, and the globe turns on an axis, the ends of which are the poles. Such a globe may be used to illustrate the daily motions of the heavenly bodies, as well as other astronomical phenomena. To use the globe, however, we must set it for the particular latitude where we wish to note these motions. To do this, it is necessary to elevate its north pole to an angle above its horizon equal to the observer's latitude, for we have learnt that the altitude of the pole above the horizon is always equal to the latitude of the observer. Having set the globe, we shall see, on turning the globe round its axis, the path of any particular star, and be able to note the extent of its circuit above the horizon. Thus if the pole of the globe be elevated 90° so as to point to the zenith, we shall represent the situation of an observer at the north pole, and the stars will be seen to describe circles parallel to the horizon. If now we place the poles of the globe in the horizon, we are able to understand the position of an observer at the equator, for on turning the globe all the stars will be seen to describe circles perpendicular to the horizon, the circles diminishing in size as we pass from the equator to either pole. When the pole of the globe is elevated to 51½°, we see the motion of the stars as an observer at London does.

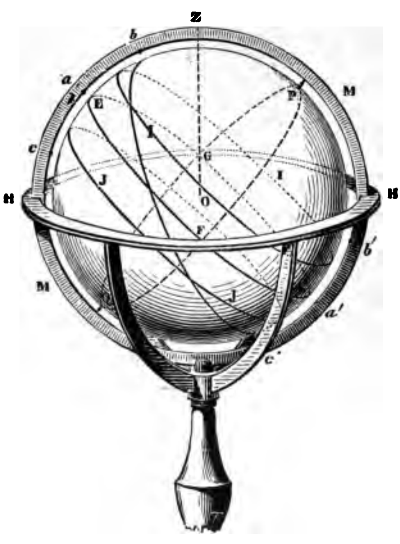


FIG. 293.—Celestial globe, set for the latitude of London.

We may also use the celestial globe to represent the various diurnal courses of the sun at different latitudes, and thus to examine the variations

in the length of day and night. In Fig. 293 the globe is set for the latitude of London, the arc HP being $51\frac{1}{2}°$. The same wooden ring HFH represents the horizon, and the meridian is represented by the brazen ring HZM passing through the zenith Z and the pole P, and this meridian meets the horizon at right angles. A great circle drawn perpendicular to the polar axis, of which one half, FEG, is above the horizon, represents the celestial equator, or equinoctial, and this meets the horizon at the east and west points, F and G. The observer is at O. By turning the globe on its axis PQ, it will be seen that when the sun is on the equator (a small piece of paper may be gummed on in position to represent the sun) it will, in the course of one revolution, be above the horizon for half its path and below the horizon for another half, rising exactly east and setting exactly west. Day and night are thus seen to be equal when the sun is on the equator. Now, the sun's yearly path is on the ecliptic, the line crossing the parallel circles in the figure, and this crosses the equator only at the vernal and autumnal equinoxes. After March 21 the sun passes north of the equator, and its diurnal path ceases to be a great circle and becomes a small circle parallel to the equator, the dimensions of which gradually decrease until it reaches a declination $23\frac{1}{2}°$ (more exactly 23° 27′) north of the equator on June 21, the date of the summer solstice. The point *b* indicates the position of the summer solstice, the arc *ab* being $23\frac{1}{2}°$. The small circle II represents the daily path of the sun at a date between March 21 and June 21, and it is plain that the part of this circle above the plane of the horizon is greater than the part below it. Hence the length of day exceeds that of night. Moreover, the rising point of the sun when his daily path is on the small circle II is to the north of the east point F, its culmination on the meridian is above the point of culmination when on the equator, and its setting-point is to the north of the west point G. Increase in the sun's northern declination thus increases in the Northern Hemisphere the length of the day and the noonday altitude of the sun, and increase in noonday altitude means a diminution in the zenith distance Change of declination also causes the sun's amplitude of rising and setting to change. A small circle parallel to II and passing from *b* to *b′* would represent the sun's daily path when its declination is at a maximum, and when, therefore, those qualities that increase with increase of declination north are at a maximum. *After the summer* solstice the sun begins, in his movement on *the ecliptic (see Fig. 259),* to return to the equator, which he reaches again on

FIG. 294.—Celestial globe, set for latitude 75° N.

September 22, the autumnal equinox, when the days and nights are again equal. After September 22 the sun's southern declination decreases; his daily path becomes a small circle of the celestial sphere parallel to the plane of the equator and to the south of it. This circle decreases in size until the winter solstice is reached, December 22. The diurnal path of the sun on a day between the autumnal equinox and the winter solstice is represented by the small circle JJ. It is easy to see that the greater part of this circle is below the plane of the horizon, and that when the sun is on this circle day must be shorter than night, the altitude of the noonday sun must be less than at the equinox, and that when the sun is below the equator he rises to the south of east and sets to the south of west. A small circle parallel to J J and passing from *c* to *c'* would represent the sun's daily path when its southern declination is at a minimum, and when, therefore, the days are shortest and the midday altitude least. From December 22 the sun passes back towards the equator and a series of changes in the relative lengths of the days and nights is repeated in inverse order, until, when the sun reaches the vernal equinox in the course of 365¼ days, the cycle of changes is complete. By elevating the pole to a greater height above the horizon, we shall find that the portion of the sun's daily path above the horizon after he leaves the vernal equinox increases with increase of latitude, until, at an elevation of 66½°, the sun at the summer solstice would just skirt the northern horizon at midnight, so that the longest day at this latitude would be 24 hours. At the winter solstice the sun at noon would only just reach the horizon, so that the shortest day would be a day without the sun.

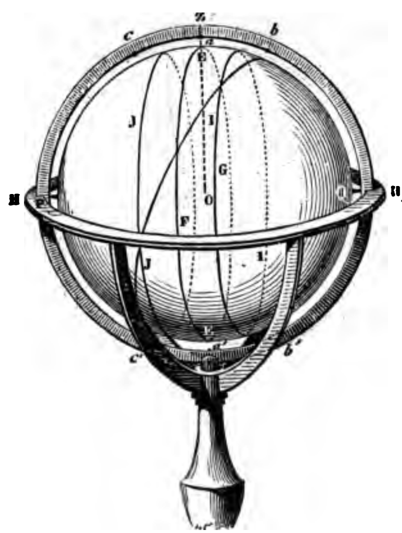


FIG. 295.—Celestial globe set for equator.

Going to a still higher latitude, as 75° N., where the pole is only 15° from the zenith, we should find that the sun in his daily path after the vernal equinox remained still longer above the horizon each day, and as his declination gradually increased, the whole of the diurnal path day after day for 103 days would be above the horizon. Fig. 294 shows a globe set for a northern latitude of 75°. When the sun is on the equator at this latitude, as at any other latitude north of the equator, he rises in the east, sets in the west, and day and night are equal. But as he passes northward in his path along the ecliptic, the portion of his daily path that appears above the horizon rapidly increases, and soon the whole of the path day after day is above the horizon. Thus in the figure the small circle II, representing his daily path as before at a date intermediate between the vernal equinox and the summer solstice, only just reaches the horizon. At a latitude of 75° N. a little calculation will show that, after a declination of 15° N. is

reached, the whole of the sun's daily path will be above the horizon until the sun attains its maximum declination $23\frac{1}{2}°$ N., and returns again to that of $15°$ N. It will be noted that the greatest noonday altitude of the sun at this latitude is only $15° + 23° = 38\frac{1}{2}°$. Thus is explained the phenomenon of the midnight sun within the Arctic Circle. The decrease in the length of day and night as the sun passes south of the equator, and the continuous darkness of winter for many days at this latitude will be readily understood. Passing to the north pole itself, we should there find the sun's daily path to be in small circles exactly parallel to the horizon. The sun at the summer solstice would perform his daily circuit of the heavens in a circle always $23\frac{1}{2}°$ above the horizon, at the equinoxes his path would be on the horizon, and at the winter solstice his path would be on a circle $23\frac{1}{2}°$ below the horizon (see Fig. 263). The path at intermediate dates can be easily realized.

Passing to the extreme of this, to the equator, an observer there would see the sun perform his daily path in vertical circles perpendicular to the plane of the horizon. Fig. 295 shows a globe set for latitude $0°$. Day and night would always be equal, as one half of the sun's daily path would always be above the horizon, and one half always below. The sun would be twice in the zenith. At midsummer he would have a zenith distance of $23\frac{1}{2}°$ north of the equator, and at the midwinter a zenith distance of $23\frac{1}{2}°$ south of the equator. The amplitude of his rising and setting points would vary to the same extent. We add a table giving the number of days during which the sun does not set in summer nor rise in winter at various latitudes in the Northern Hemisphere :—

North Latitude.	Sun does not set for about	Sun does not rise for about
66° 33′	1 day	1 day
70	65 days	60 days
75	103 ,,	67 ,,
80	134 ,,	127 ,,
85	161 ,,	153 ,,
90	186 ,,	179 ,,

The difference between the number of days on which the sun never sets and the number on which he does not rise is accounted for by the fact that he takes about seven days longer to move through the portion of his yearly path north of the equator than he takes to move through the portion south of the equator (par. 287).

We may also remark that in speaking of the length of day at different latitudes, no account is taken of refraction (par. 86). At the horizon the mean refraction is about 33′, and the effect of this is to accelerate the time of sunrise and to retard the time of sunset. As the mean apparent diameter of the sun is about 32′, the sun appears to be just above the horizon when in reality it is just below.

QUESTIONS IN PHYSIOGRAPHY.

Original and Selected.

Answers should be illustrated by diagrams whenever possible. Keep the answers corresponding to the various parts of the same numbered question distinct.

QUESTIONS ON CHAPTER I.

1. Explain the terms *matter*, *substance*, and *body*. What is meant by saying that matter has a "molecular structure"?

2. If you take a jug of muddy water from the seashore, how could you remove the mud and other suspended matter? What will become of the salt in solution?

3. Define and distinguish the three forms or states in which matter exists. Is the distinction always sharp and clear?

4. Explain the terms *impenetrability*, *cohesion*, and *rigidity*, as applied to various bodies.

5. Describe two simple experiments to show that there is no loss of matter during solution or burning.

QUESTIONS ON CHAPTER II.

1. What is the British unit of length, and what is the metric unit of length? How is each of these units divided? What are the advantages of dividing according to the metric system?

2. Write out the metric table of area. How many square inches in a square foot, and how many square centimetres in a square metre? *Ans.* 144; 10,000.

3. What is a litre? How many cubic centimetres does a litre contain? How many litres make a kilolitre? *Ans.* 1000; 1000.

4. What is a gram? Write out the metric table of weight. What is the equivalent in English weights of a gram and a kilogram? What is the connection between the metric unit of mass and the metric unit of volume?

5. What is the general unit of time? How would you arrange a simple pendulum to beat seconds?

6. Explain the common system of *angular measurement*. Define the word *degree* as used in angular measurement.

QUESTIONS ON CHAPTER III.

1. State the general law of gravitation. Distinguish between the mass and weight of a body.

2. Define specific gravity. How would you find the specific gravity of milk?

3. What is meant by the principle of Archimedes? How would you prove this principle?

4. How can you find the volume of water displaced by a solid body which sinks in water? What does this show?

5. Explain with sketch how you would find the specific gravity of an iron key. If the key weighs 100 grams in air and 86⅓ grams in water, what is its specific gravity, and its volume? *Ans.* 7·31; 13·66 c.c.

6. A fifty-gram flask will hold 45 grams of ammonia solution and 84 grams of sulphuric acid; what is the specific gravity of those two liquids? *Ans.* 0·9 and 1·68.

7. Under what conditions do bodies sink or float in a liquid? How could you show that the mass (weight) of water displaced by a floating object is equal to the whole mass (weight) of the object?

8. Explain the use of the term *density*. How is density related to *mass* and *volume*?

9. Find the weight of 24 cubic inches of copper, the specific gravity of which is 8·82, having given that a cubic foot of water weighs 1000 ounces. *Ans.* 122·5 oz.

10. If a body floats in water with one-fifth its volume above the surface, what will be the weight of one c.cm. of the body?

Solution. Since the weight of a floating body is equal to the weight of the fluid displaced and four-fifths of the body is immersed; therefore the whole body weighs four-fifths the weight of the same bulk of water. Hence also 1 c.cm. of the body weighs four-fifths the weight of 1 c.cm. of water, *i.e.* ⅘ gram.

QUESTIONS ON CHAPTER IV.

1. Explain the terms *motion*, *rectilinear motion*, *uniform rectilinear motion*, and *velocity*.

2. Express in feet per second a velocity of 50 yards per minute, and find how long a point moving at the rate of 6 feet per second takes to move 120 yards. *Ans.* 2½ feet per sec.; 1 minute.

3. What is meant by *acceleration*? What is the acceleration that gravity can produce, and how would you find it?

4. Through what space will a body fall in 6 seconds, and what velocity will it have at the end of that period? *Ans.* 576 feet; 192 feet per sec.

5. Explain the meaning of the term *inertia*, and give three examples of this property of bodies.

6. What is meant by the terms *force* and *momentum*? How can each be measured? A body whose mass is 6 lbs. has a momentum of 576 units. What is its velocity? *Ans.* 96 feet per sec.

7. State the principle called the *parallelogram of forces* and describe how its truth may be proved experimentally.

8. Two forces P and Q, P being 6 lbs. and Q being 17½ lbs., act (1)

both due north ; (2) P due north and Q due south ; (3) P due north and Q due east. Find the magnitude and direction of the resultant in each case.

Ans. (1) $23\frac{1}{2}$ lbs. due north ; (2) $11\frac{1}{2}$ lbs. due south ; (3) in this case the forces act at right angles, 18·5 lbs. in a direction more east than north.

9. Illustrate by means of an example what is meant by "*the resolution of a force.*"

10. State Newton's third law of motion, and give examples.

11. Define *force, momentum*, and *stress*. What is the momentum of a body whose mass is half a hundredweight, and whose velocity is 20 feet per second? *Ans.* $56 \times 20 = 1120$ units of momentum.

12. Explain how rectilinear motion is converted into circular motion. Discuss the term "*centrifugal force.*"

13. What is "*angular velocity*," and how is it measured?

14. Explain (*a*) Why it is an advantage to run before taking a leap.
(*b*) Why the velocity of a body falling freely continually increases.

QUESTIONS ON CHAPTER V.

1. Explain what is meant by *parallel forces*. How would you find experimentally the resultant of two like parallel forces?

2. Two like parallel forces of 9 lbs. and 12 lbs. act at points $2\frac{1}{2}$ feet apart. Find the magnitude, direction, and position of the resultant.

Solution. The *magnitude* of $R = 9 + 12 = 21$ lbs. The *direction* is the same as the two forces and parallel to them. The *position* of the resultant divides the distance between the forces in inverse proportion to the forces. Let the distance from the 9 lbs. be x inches. Then the distance from the 12 is $(30 - x)$ inches. $\therefore 9x = 12(30 - x)$; $\therefore 9x + 12x = 360$; $\therefore 21x = 360$; $\therefore x = 17\frac{1}{7}$ inches.

3. State and exemplify the principle of the lever.

4. Give examples of the various classes of levers. Which kind has no mechanical advantage, and why is it used?

5. A lever of the first kind is 20 feet long, and a force of 21 lbs. is made to raise a weight of 39 lbs. with it. What is the length of the power arm? *Ans.* 13 feet.

6. Explain by means of an example the use and advantage of the single movable pulley.

7. On an inclined plane when the power is acting parallel to the plane, what is the relation of the power to the resistance? How would you show this relation experimentally?

8. Give an example of the practical use of the screw. If the pitch of a screw be half an inch, and the length of the lever by which it is turned be two feet, what force will be required to raise one ton, friction being neglected? *Ans.* $7\frac{14}{33}$ lbs.

QUESTIONS ON CHAPTER VI.

1. Describe how you would find the centre of gravity of an irregular piece of sheet-iron. How would you prove that the point found was the true centre of gravity?

2. What conditions must be fulfilled if a body is to remain at rest upon a surface?

3. When is the equilibrium of a body *stable?* When is it *unstable*, and when *neutral?*
4. What position is taken up by a *suspended* body, and why? In loading a cart, where should the heavy objects be placed, and why?
5. Where is the centre of gravity of a boy's iron hoop? How would you find it?

QUESTIONS ON CHAPTER VII.

1. What is meant by the term *work?* Mention cases (*a*) in which a force is doing work, (*b*) in which a force is doing no work. How much work is done in raising half a ton two yards high? *Ans.* 6720 foot-lbs.
2. Distinguish between *work* and *energy*. How can it be shown that a falling stone and a reservoir of water possess energy?
3. Describe experiments to show (*a*) that energy may be transferred from one body to another, (*b*) that the energy of visible motion may be transformed into heat, (*c*) that the energy of heat may be transformed into the energy of visible motion.
4. How can you show (*a*) that an electrified body possesses energy, (*b*) that an electric current possesses energy? Into what other forms of energy is that of the electric current often transformed?
5. Illustrate by three examples "the energy of chemical action."
6. What is meant by *radiant energy* or the *energy of radiation?* How does the sun's radiant energy reach the earth?

QUESTIONS ON CHAPTER VIII.

1. How do you distinguish between the heat of a body and its temperature?
2. How would you show (*a*) that a solid body expands on being heated, (*b*) that some solids expand more than others?
3. Describe with sketch the construction of a simple water-thermometer. What liquid has less expansibility than water?
4. What is there special about the expansibility of gases? Explain the construction and use of a differential air-thermometer.
5. Carefully explain how you would graduate a thermometer, supposing the tube to have been properly supplied with mercury and sealed.
6. Describe some form of maximum thermometer, and state facts about its use.
7. To what extent does water behave exceptionally when heat is added or withdrawn? How could you show that water has its maximum density at 4° C.?
8. How would you show (*a*) that silver is a better conductor of heat than iron, (*b*) that water is a bad conductor of heat, (*c*) that air conducts heat badly, (*e*) that wood is a worse conductor than iron?
9. Explain with sketch the mode in which a vessel of water placed upon the fire is heated.
10. Give some account of what is spoken of as "radiant heat." Is the term strictly correct?
11. How is heat measured? What is meant by saying that iron has a greater capacity for heat than lead?

12. What is meant by *specific heat?* Why is the great specific heat of water important?

13. Ice at 0° C. is placed in water at 0° C., and the vessel is slowly heated. What changes would a thermometer placed in the vessel undergo?

14. Distinguish between *evaporation* and *ebullition* or boiling. On what conditions does the boiling-point of water depend?

15. How can you show that heat-energy is required to turn liquid water into water vapour? What becomes of this heat-energy, and under what circumstances may it be made to reappear?

QUESTIONS ON CHAPTER IX.

1. Mention reasons for believing that light travels in straight lines. Explain how you would obtain an inverted image of a candle flame in a darkened room. What should be done to increase the size of the image?

2. What do you understand by the terms *shadow*, *umbra*, *penumbra?* Add drawings to illustrate your answer.

3. Under what circumstances is light reflected? What is the law of reflection, and how would you illustrate it?

4. When a plane mirror is made to rotate, how does a reflected beam of light behave?

5. How are the images of trees, houses, etc., formed in smooth water, and why do they appear inverted?

6. What happens to rays of light (*a*) when they pass obliquely from one medium into a denser medium, (*b*) when they pass from one medium into a rarer medium?

7. State and explain two curious deceptions caused by the refraction of light.

8. What two effects are produced when light is sent through a prism? Explain these effects.

9. How would you proceed in order to obtain a prismatic spectrum? How can the various colours of the spectrum be put together again, and what would be the effect?

10. Why are some flowers red and others blue? What colour would each have in the blue part of the spectrum?

QUESTIONS ON CHAPTER X.

1. Define the terms *element* and *compound*, giving three examples of each. What is a binary compound?

2. Explain how you would prepare and collect oxygen.

3. Describe experiments to illustrate the properties of oxygen, and carefully explain what is meant by *combustion*.

4. Briefly describe two modes of preparing hydrogen gas. What substance is formed when hydrogen burns?

5. State the chief physical properties of water. How would you show that ordinary water contains air in solution?

6. What apparatus would you require to show that water is a compound of oxygen and hydrogen? In what proportion do those two elements exist in water, (*a*) by volume, (*b*) by weight?

7. What is the composition of dry air? How would you show that ordinary air contains water vapour?

8. How would you obtain nitrogen from the air, and what experiments would you perform to show the properties of this gas?

9. How can the oxygen of the air be made to combine with copper to form copper oxide? How can the oxygen of the copper oxide be taken away again?

10. State carefully the distinctions between a chemical compound and a mechanical mixture. To which class do air and water belong? Give reasons for your answer.

QUESTIONS ON CHAPTER XI.

1. Describe the chief varieties of carbon and the special properties of each.

2. How would you prepare and collect carbon dioxide gas?

3. What happens (*a*) when a piece of sodium is placed on water; (*b*) when a dry glass is placed over a burning candle; (*c*) when carbon dioxide is shaken up with lime-water?

4. A piece of chalk or other form of limestone is strongly heated. What change takes place in its weight and composition?

5. Distinguish between limestone and lime. What happens (*a*) when lime is strongly heated, (*b*) when water is poured upon it?

6. Contrast the properties of acids and alkalies. What is formed when an acid is added to an alkali?

7. Under what conditions does iron rust? What occurs when iron rusts?

8. What are the chief physical properties of mercury? How would you find its specific gravity? How could you obtain mercury from mercuric oxide?

9. What is the composition of quartz and flint? How would you distinguish quartz from glass? What class of compound is formed when silica unites with a metallic oxide?

QUESTIONS ON CHAPTER XII.

1. Describe what can be seen on examining a piece of coarse sandstone and a piece of granite.

2. What is a rock? a mineral? Mention the most abundant rock and the most abundant mineral in the earth's crust.

3. By what properties are minerals recognized? Explain the meaning of the terms *cleavage* and *hardness* as applied to minerals.

4. Give some account of the mineral *felspar.*

5. Give an account of the crystalline form and chemical composition of *quartz.* What is its position on the scale of hardness?

6. What do you know of the minerals, *mica*, *hornblende*, and *gypsum*?

7. What varieties of calcite are known? How would you distinguish calcite from quartz?

8. Tell what you know about *mica.*

QUESTIONS ON CHAPTER XIII.

1. Point out the chief differences between stratified and unstratified rocks. By what other names is each of these classes known?

2. Distinguish between rocks that have a crystalline stıucture and those that are non-crystalline, naming members of each class.

3. Describe a piece of *conglomerate* and a piece of *sandstone*.
4. What do you know of the formation of *clay* and *shale*?
5. Carefully state—
   (*a*) The chemical composition of coral.
   (*b*) The parts of the world where coral rocks abound.
   (*c*) Why coral is spoken of as an *organic* rock.
6. Under what conditions does the coral polyps live and thrive? Is coral rock the *work* of the coral polyps?
7. Give a short account of the chief varieties of limestone.
8. What is the chemical composition of *coal*? How does it differ from peat?
9. What are stalactites and stalagmites? How are they formed?
10. Classify the igneous rocks: (1) according to mode of occurrence; (2) according to chemical composition.
11. Give some account of the different varieties of *lava*.
12. Describe carefully the rock *basalt*. What is its chemical composition?
13. Give a brief description of obsidian and pumice.
14. What are metamorphic rocks? How have they been produced? Mention four examples of this class.
15. Compare and contrast *gneiss* and *granite*.
16. Explain what is meant by lamination and foliation.
17. What do you know of (*a*) kaolin, (*b*) rhyolite, (*c*) mica-schist?

QUESTIONS ON CHAPTER XIV.

1. How does the temperature of the earth's crust vary as we pass into it? What is meant by "the stratum of invariable temperature"?
2. Give an account of the chief events that occur during a volcanic eruption.
3. Carefully enumerate and describe the chief products of a volcanic eruption.
4. Tell what you know about a *lava stream*. What are *acid* lavas and *basic* lavas?
5. Enumerate the different varieties of volcanic cones, and illustrate by means of a diagram the structure of a composite cone.
6. Point out the mistakes in the following: "A volcano is a burning mountain that ejects smoke and ashes."
7. Write a short description of each of the following: a *volcanic bomb*, *scoriæ*, *lapilli*, a *lateral crater*, a *fumarole*.
8. Trace out the line of volcanoes that borders both sides of the Pacific Ocean.
9. In what parts of the world are earthquakes most frequent? How is the point of origin of an earthquake shock ascertained?
10. What proofs have we that variations of land level occur in different parts of the world? Carefully describe a *raised beach*.
11. On what shores is the land now sinking? What proofs of land subsidence may be pointed to?
12. What is meant by *volcanic ash*, a *volcanic dyke*, a *parasitic cone*, a *solfatara*?
13. What are the most striking effects of earthquakes? Is it right to say that earthquakes have raised to heaven the ocean bed?

QUESTIONS ON CHAPTER XV.

1. What do you know of the dust particles present in the atmosphere?

2. When is the air said to be *dry?* How is the humidity of the air ascertained?

3. How would you show that the air exerts pressure in all directions? What is the average amount of pressure that it exerts?

4. Describe the construction and action of a syringe.

5. Explain the construction and action of a common suction pump.

6. How is a *cistern barometer* constructed? What would be the effect of (*a*) leaning the tube to one side, (*b*) making a small hole in the top?

7. What is meant by "the height of the barometer"? How is the exact height obtained (*a*) in Fortin's barometer, (*b*) in a siphon barometer?

8. What are the advantages of mercury (*a*) for thermometers, (*b*) for barometers?

9. State the law that shows the relation between (*a*) the volume and the pressure of a gas, (*b*) between the density and pressure of a gas. Describe an experiment to prove the former.

10. How do the pressure and the density of the air vary with increase of altitude? What would be the effect of taking a barometer, (*a*) up a mountain, (*b*) down a coal mine?

11. What causes lead to changes in the atmospheric pressure? Why does a barometer usually rise on the approach of fine weather?

12. Explain the words *isobar* and *isotherm*.

13. State the nature of the corrections that must be applied to the readings of barometers when these readings are taken at different places.

14. How is the air warmed? Why is it hotter (*a*) in summer than in winter, (*b*) in Egypt than in Scotland, (*c*) at sea level than upon the summit of a neighbouring mountain?

15. Give a clear account of land and sea breezes.

16. In what regions of the earth do the trade winds blow? What is their cause? Why do they not blow exactly north and south?

17. Give some account of the monsoons.

18. What are the characteristics of a *cyclone* and an *anticyclone?*

QUESTIONS ON CHAPTER XVI.

1. State as accurately as you can—
   - (*a*) The two chief solids in solution in sea-water, and the percentage amount of these solids.
   - (*b*) The way in which you could obtain these solids from a quantity of sea-water.
   - (*c*) The sea that contains the largest percentage of solid matter in solution.
   - (*d*) The average density or specific gravity of sea-water.

2. Give an account of the mode in which a deep-sea sounding is made, and how a specimen of the ocean floor is brought up.

3. Describe, with the aid of a sketch map, the floor of the Atlantic Ocean.

4. What do you know about the temperature of the ocean, (*a*) at the surface, (*b*) at great depths?

5. Explain how the sea acts in destroying the coast in various districts.

6. Enumerate the different varieties of deposits that are found on the ocean floor, and say at what depth each kind is met with.

7. What becomes of—

   (*a*) The calcium carbonate dissolved in sea-water?
   (*b*) The slight quantities of silica dissolved in sea-water?
   (*c*) The angular boulders broken off a cliff by the action of the waves?
   (*d*) The calcareous shells of Foraminifera that fall into the deepest parts of the ocean?

8. Compare the microscopic appearance of chalk and Globigerina ooze.

9. What is the average percentage of solid matter dissolved in sea-water? Why are some inland seas salter than the open ocean, while some are less salt?

10. What different varieties of ooze have been found on the ocean floor?

11. What is meant by sea-level? What causes disturb a mean sea-level?

12. From what sources does the sea obtain the salts it holds in solution? What organisms make use of the small percentage of silica in sea-water?

QUESTIONS ON CHAPTER XVII.

1. What do you consider to be the chief causes of ocean currents? How have the direction and speed of ocean currents been ascertained?

2. Give some account of the origin, course, and effects of the Gulf Stream.

3. What is the main current of the Pacific? Describe its course.

4. What do you know of (*a*) the Cold Wall, (*b*) the Sargasso Sea, (*c*) the effect of the monsoons on the currents of the Indian Ocean?

QUESTIONS ON CHAPTER XVIII.

1. At what temperature does sea-water freeze? How is it that the water from melted sea-ice is almost fit to drink?

2. Describe the *ice-foot*, an *ice-field*, and an *ice-floe*.

3. Explain the origin of icebergs. Compare the portions of a berg below water and above water. What ultimately becomes of an iceberg and its burden?

4. How do Antarctic icebergs differ from Arctic icebergs? What is the Ice Barrier of the Antarctic?

QUESTIONS ON CHAPTER XIX.

1. Under what circumstances does water evaporate into the air freely? What leads to condensation of this water vapour?

2. Of what does dew consist? From what sources is it derived? What atmospheric conditions are favourable to its deposition?

3. Of what does a fog consist? What part do dust-particles play in its production? Where are fogs most frequent?

4. Explain the construction and use of the rain gauge.
5. Write down—

   (*a*) The mean annual rainfall of the west side of Britain.
   (*b*) The mean annual rainfall of the east side of Britain.
   (*c*) The main cause of the difference between those two.
   (*d*) The place in England with the greatest annual rainfall, and the place with the least.

6. In what parts of the world is there no rainfall? Account for this extreme dryness in three cases.

7. What portions of the globe have *rainy seasons*, and when do these rainy seasons occur?

8. Why has the eastern side of the British Isles less rainfall than the western side? What is the mean annual rainfall of the town where you live, and how is it found?

9. Draw some forms of snow-crystals. In what parts of the world is snow never seen at the sea-level?

10. Define *snow line*, and give the height of the snow-line at the equator, in Central Europe, and in Scotland. What circumstances influence the height of the snow-line besides latitude?

11. Account for (*a*) the great rain-fall on the Khasia Hills in Assam; (*b*) the arid nature of the desert of Gobi; (*c*) the inhospitable climate of Labrador; (*d*) the genial warmth of North Italy.

12. How would you find (*a*) the mean rainfall for the month of January at any place, (*b*) the hygrometric state of the air on a given day?

QUESTIONS ON CHAPTER XX.

1. Explain the terms *denudation*, *erosion*, and *débris*, and name the chief agents of denudation.

2. Give some account of the action of the atmosphere and the rain upon rocks.

3. Point out the action of rivers on the surface of a country. What is a *river-terrace*?

4. What rivers form deltas? Of what does a delta consist? How does it happen that the bed of a river in a delta may be higher than the general level of the land around?

5. What are *surface springs*, and how are they formed? Mention other varieties of springs, and describe one of them.

6. What causes a glacier to move? How has the motion been proved? Compare the rate of motion in Alpine and Arctic glaciers.

7. In what way does a glacier act as an agent in transporting rocks? Why are the waters that issue from a glacier usually very turbid?

8. By what indications do we infer the presence of glaciers in districts where they are no longer found?

9. Briefly describe each of the following: pot-hole, gorge, canon, alluvium, sand-bank, glacier table, moulin, *roche moutonnée*, *dyke*.

10. What are *contour lines*? And what can be learnt from their inspection?

11. Account for the following statements:—

    (*a*) All the rivers run into the sea, yet the sea is not full.
    (*b*) The sea owes much of its salt to fresh water streams.
    (*c*) There would be no snow if it were not for the heat of the sun.

QUESTIONS ON CHAPTER XXI.

1. Describe the construction and behaviour of a simple magnetic needle.

2. How would you show (*a*) that the like poles of two magnets repel one another; (*b*) that the strength of the magnet's attractive force is greater at one of its poles than at the middle of the magnet?

3. Explain what is meant by the *magnetic field* of a magnet, and how this field can be examined.

4. Describe the phenomenon known as *magnetic induction.*

5. Give a short account of the *declination* of the compass needle.

6. Explain how a magnetic needle dips from the horizontal in different localities.

7. Give a short account of the magnetic condition of the earth.

8. Describe a magnetic chart.

9. Give a short description of a mariner's compass. How does it differ from a land compass?

10. Explain how you would use a simple magnet compass (*a*) to find a north and south line; (*b*) to ascertain whether a piece of steel has been magnetised or not.

QUESTIONS ON CHAPTER XXII.

1. Explain the terms *sphere*, *great circle*, *celestial sphere*, *zenith*, *horizon.*

2. Show by means of a figure what is meant by the *altitude* and *azimuth* of a star.

3. Explain the use of the terms *declination* and *right ascension.*

4. Give an account of the construction and use of the sun-dial.

5. What is the shape of the earth? How has it been found that it is somewhat flattened at the poles?

6. What is meant by the *culmination* of a heavenly body? When does this occur?

7. Explain the mode of indicating the position of a place on the earth's surface. What places have their noon at the same time? Under what circumstance is a day gained in going round the world?

8. When it is noon at London what is the time (1) at New York, long. 73° 55′ W.; (2) at Constantinople, long. 29° E.?

Ans. 7 h. 4 m. a.m. at New York; 1 h. 56 m. p.m. at Constantinople.

9. Define the term *meridian.* How would you find the meridian?

10. Describe the apparent diurnal motion of the heavenly bodies.

11. State two proofs of the earth's rotation on an axis. How do you know the direction of this rotation?

12. Give an account of the daily apparent movements of the stars to an observer at the equator.

13. Describe the sun's apparent eastward motion among the stars, and show by a diagram that a real motion of the earth in the opposite direction will explain this phenomenon.

14. What is the evidence in favour of the annual revolution of the earth? When is the earth's velocity in its orbit greatest?

15. What is the shape and size of the earth's orbit? Explain the terms *perihelion* and *aphelion.*

16. How are the plains of the earth's orbit, of the ecliptic and of the equator related to each other?

17. State Kepler's laws, and explain the first and third.

18. Give an account of the different kinds of *day* spoken of in astronomy. Why does the true solar day vary in length?

19. Give an account of the yearly changes in the position of the stars as seen at midnight.

20. How does the shadow of a vertical stick indicate the midday altitude of the sun? When is this shadow shortest, and with what line does it then coincide?

21. What are the causes of the seasons? What effect would be produced on the seasons were the earth's axis to be perpendicular to the plane of its orbit or to lie in it?

22. "Within the Arctic circle at the summer solstice we can see the midnight sun due north, but at the winter solstice we do not see the sun even at noon." Explain this, illustrating by means of diagrams.

23. When are the days and nights equal in all parts of the world, and why are they not always equal in all parts? Where are they always equal?

24. Give the length of the longest day at the *pole*, in latitude 75°, 50°, 30°, and at the *equator*.

25. Draw a diagram to show the apparent altitude of the sun as seen from London at midsummer and midwinter. (Figs. 275 and 276 may be used, a point between the Arctic Circle and the Tropic of Cancer being taken for London. A line from the centre of the earth through the position of the observer will give the direction of the zenith.)

26. Explain fully why it is hotter in summer than in winter.

27. What yearly changes are there in the appearances of the stars, and how are they accounted for?

28. How often is the sun vertically overhead for a place within the tropics, and on what dates for a place on the equator?

29. What decides the length of the year exactly, and what decides how many whole days there are in it?

30. Decide the daily path of the sun as seen by an observer at the pole during a year.

31. Give some account of the distribution of the sun's light and heat on different parts of the earth.

33. Why do the stars rise a little earlier on each succeeding evening? What produces the difference between a solar and a sidereal day?

34. "The sun keeps describing a larger and larger arc in the sky as the season advances." Account for this.

35. Explain the following:—The constant parallelism of the earth's axis; solstice; torrid zone; mean solar time; ecliptic; azimuth; Foucault's pendulum experiment.

36. Carefully describe the gradual change in the length of day and night in the Temperate Zones.

37. What difference would be seen in (1) the daily path of the sun, (2) the daily path of the stars, by an observer in the south of England, and by an observer in the north of Scotland?

38. How would you recognise the eastward motion of the sun in the ecliptic?

39. What would be the effect on the seasons (*a*) if the earth's axis were inclined at an angle of 45° to the ecliptic; (*b*) if the earth's axis were perpendicular to the ecliptic?

40. Explain what is meant by the aberration of light. How does it affect the position of a star?

41. By means of a gnomon, or vertical pillar, how could you find (*a*) the north and south line, (*b*) the date of the solstices?

42. Show why a sidereal day is shorter than a solar day. What is a *mean* solar day? When is the true solar day longest?

43. Explain the terms *declination* and *right ascension*. What causes the variation in the sun's declination during the year, and what is the result of this variation?

44. How may the shape of the earth's orbit be determined?

45. Show by a diagram the variation in the declination and amplitude of the sun (*a*) at the equator, (*b*) in latitude 45° N.

46. Where and when can the sun be seen at midnight? In what part of the sky is it then visible?

47. What is meant by (*a*) the aberration orbit of a star? (*b*) the annual parallax of a star? What do these phenomena prove?

48. Why do the seasons differ in length?

49. What is "Greenwich mean time," and how is it found?

50. Tell briefly how you would find (*a*) the position of the pole star; (*b*) the position of the celestial equator; (*c*) the time of the earth's rotation.

51. Briefly explain (*a*) why the sun never reaches the zenith in any part of the British Isles; (*b*) why it is warmest in the British Isles when the earth is farthest from the sun; (*c*) why the hottest part of the year in the British Isles is usually about the end of July.

52. Write down (*a*) how many times the earth rotates in a year, (*b*) the altitude and zenith distance of the pole star at London, (*c*) a mode of finding the shape of the earth's annual orbit.

QUESTIONS ON CHAPTER XXIII.

1. Give a short account of the physical condition of the sun.

2. Describe the orbital motion of the moon. Distinguish between the different kinds of month.

3. What do you know of the physical condition of the moon?

4. With the aid of a drawing give some account of the phases of the moon.

5. When does an eclipse of the moon occur? When is a lunar eclipse total?

6. State the conditions under which the sun is eclipsed. Where is such an eclipse visible?

7. What is an annular eclipse of the sun? Explain when it may happen? Why is there never an annular eclipse of the moon?

8. How is the exact size of the earth found?

9. In what way can the density or specific gravity of the earth be found?

10. How can the distance of the sun be found by observation of the eclipses of Jupiter's satellites?

11. Explain the meaning of the term *parallax*. Give illustrations.

12. How can the distance and the size of the moon be determined?

EXAMINATION PAPERS.

First Stage, or Elementary Examination.

You are permitted to answer SIX *questions. Of these, two must be taken from each series.*

1897. May.

Series I.

1. (*a*) A flask is taken, phosphorus put at the bottom of it, a cork inserted, and the whole weighed. The cork is then removed from the flask, the phosphorus set fire to, the cork rapidly replaced, and the whole apparatus weighed again. What will be the result of this second weighing as compared with the first? State the reason of this.
   (*b*) State exactly what goes on inside the flask.
   (*c*) Why does the phosphorus soon cease to burn?
   (*d*) What shall we find in the flask upon opening it? (20)
2. A brass button, when rubbed on a school-form, becomes hot.
   (*a*) What is the source of this heat?
   The button is placed on a table, and in a few minutes it becomes cool.
   (*b*) What has become of the heat? (20)
3. What is a prism? Give a diagram showing the course of a ray of white light through one made of glass. Which colour is refracted most, and which least? (20)
4. What is the composition of water? How would you prepare water synthetically? Describe the apparatus usually employed. (20)

Series II.

5. State what happens to the column of mercury—
   (*a*) When a barometer is taken down a mine, giving the reason of any change that takes place.
   (*b*) When a thermometer is taken down a mine, giving the reason of any change that takes place. (15)
6. (*a*) Why do the lower parts of the ocean never get warm?
   (*b*) Why is the surface-water of the ocean sometimes salter than that below?
   (*c*) Why is ocean-water near land sometimes less salt than that far away?
   (*d*) Why are warm currents, like the Gulf Stream, confined to the surface of the ocean? (15)
7. Give examples of four kinds of limestone, each of which is built up

of a different kind of organism, and state the nature of the organism in each case. (15)

8. (*a*) How has it been proved that glaciers move?
(*b*) What do you know concerning the *rate* of movement of glaciers? (15)

Series III.

9. What causes an eclipse of the sun? How many different kinds are there? Give the reasons for each. (15)

10. Explain what is meant by the "local time" of a place, say London. Why should the "local times" of Liverpool and Berlin at any one moment differ? (15)

11. What is the "form" of the earth? Do degrees of latitude measured in miles on the earth's surface vary? If so, state why. (15)

12. State the most important property of a loadstone. Describe a simple instrument that is based on it, and state its use. (15)

1897. June (Day Examination).

You are permitted to answer SIX *questions. Of these, not less than two or more than three must be taken from the first series. The rest must be taken from the second series.*

Series I.

1. You are given a flask with a narrow neck, a balance to which this can be attached for weighing, and two bottles containing respectively rain-water and sea-water. How would you proceed to determine the specific gravity of the sea-water? (20)

2. (*a*) Take a piece of chalk and heat it for some time in a Bunsen burner.
(*b*) Pour a few drops of water on the fragment.
(*c*) Throw the fragment into a bottle of water, and shake for some time.
(*d*) Take a tube and blow through the water in the bottle.
State and explain what occurs during each of these operations. (20)

3. State some properties of (*a*) oxygen, (*b*) nitrogen. What elements compose (*c*) iron oxide, (*d*) silica? (20).

4. How do we know that the earth is a magnet? At what place on the earth's surface is the dip "zero"? (20)

Series II.

5. Explain the changes which take place in the composition of the atmosphere—
(*a*) When plants are growing in it in bright sunshine;
(*b*) When dead plants are undergoing decay in it. (15)

6. Explain the mode of formation of springs. How does the water of springs differ in composition from rain-water, and what is the cause of the difference? (15)

7. Why are deltas usually formed in tideless seas? If a boring were made in a delta what kind of materials would be passed through? (15)

8. What is the chemical composition of coal? State how ordinary coal differs in composition from (1) wood; (2) anthracite. What is the nature of spore coals? (15)

9. What is meant by the plane of the ecliptic and the plane of the equator? How do they lie with respect to one another? (15)

10. State Kepler's laws, and apply them to the earth. (15)

11. State fully *one* method by which "longitude" may be determined. (15)

12. What is the cause of an eclipse of the moon? Why can a lunar eclipse be more generally observed over the earth's surface than a solar one? (15)

1898. May.

You are permitted to answer SIX *questions. Of these, two must be taken from each series.*

Series I.

1. I take 2 ounces of lead and 2 ounces of water, place them in the same beaker, and heat the beaker over a Bunsen flame. I then take two other beakers, each containing 2 ounces of cold water, and add the hot lead to the one and the hot water to the other. After stirring, I note the temperature in each case with a thermometer. State (*a*) how the thermometer readings differ, and (*b*) the cause of this difference. (20)

2. I throw a fragment of sodium of about the size of a pea into a vessel of water.

   (*a*) Describe the phenomena exhibited.
   (*b*) Explain the causes of these phenomena. (20)

3. What are the properties of hydrogen and carbon-dioxide? Describe a method of preparing the latter gas. (20)

4. State the chief differences in the properties of water in solid, liquid, and gaseous states. Under what conditions are these several states assumed by water? (20)

Series II.

5. If I take a barometer-tube, the internal sectional area of which is one-fourth of a square inch, calculate, from the known pressure of the atmosphere, the weight of mercury which would be supported in the tube. When the mercury stands at the height of 30 inches in the barometer, what is the weight of air pressing on an acre of ground?

   (There are 5280 feet in a mile [linear] and 640 acres to the square mile.) (15)

6. I take a bottle which, when exactly filled, contains 1 lb. of clean rain-water. If I fill the same bottle with sea-water, what difference of weight shall I find? I pour out these quantities of rain- and sea-water respectively into two dishes, which I place in an oven till all the water is driven off. State what I shall find left in each of the two dishes. (15)

7. (*a*) What is an iceberg?
   (*b*) How do you suppose icebergs to have been formed?
   (*c*) Why do icebergs float with part of their mass above the sea?
   (*d*) What is the proportion of the part above the water to that below? (15)

8. Explain the difference in structure between—
   (*a*) A conglomerate, and

(*b*) A breccia;
(*c*) A volcanic scoria; and
(*d*) A piece of pumice. (15)

SERIES III.

9. Explain the apparent constancy of the altitude of the pole star for any one latitude. Why do some stars never set in the latitude of London? (15)

10. Describe a sun-dial and state its use. Why does sun-dial-time differ from clock-time? (15)

11. Name three methods which prove that the earth rotates on its axis, and fully describe two of the methods? (15)

12. What is meant by the magnetic "dip"? State the method employed to determine it. Where on the earth's surface is the dip greatest? (15)

1898. JUNE.

You are permitted to answer SIX *questions. Of these, two must be taken from each series.*

SERIES I.

1. Put a pound of water into a beaker. Boil this water, and introduce into it an ounce of ice. Explain the changes that take place—
(*a*) In the water,
(*b*) In the ice.

If I introduce into a pound of water at boiling temperature two pounds of ice, explain—
(*c*) What will happen,
(*d*) The reason of this. (20)

2. Pour about three ounces of water upon half a pound of quicklime. Describe and explain the phenomena observed. (20)

3. Explain the difference between a mechanical mixture and a chemical compound. Give an illustration of each. (20)

4. Describe the Mariner's Compass. How can we determine the *true* north and south points by its means? (20)

SERIES II.

5. Cover the bottom of a shallow dish with lime-water. On this float a watch-glass containing a small quantity of spirits of wine. Set fire to the spirits of wine, and cover the whole with a bell-jar.
(*a*) State the phenomena observed.
(*b*) Explain the reason of each of these phenomena. (15)

6. I take a Florence flask and put into it some particles of red colouring matter (cochineal). I now place under the flask a lighted spirit-lamp. Show, by means of a diagram, the nature of the movements that take place in the water. How is it that the whole body of the water in the ocean is not warmed by the sun in the same way as the water is warmed in the flask? (15)

7. (*a*) Where do the stones on the surface of a glacier come from?
   (*b*) How are they arranged on the surface of the glacier?
   (*c*) What effects have these stones on the ice upon which they lie with respect to its melting?
   (*d*) What becomes of the stones at the end of the glacier? (15)

8. What chemical compounds are present in—
   (*a*) Quartzose Sandstone,
   (*b*) Felspar,
   (*c*) Limestone,
   (*d*) Rock Salt? (15)

SERIES III.

9. Define the terms *altitude*, *azimuth*, *zenith distance*, and *north polar* *'istance*. Draw a diagram in which these co-ordinates are clearly ndicated. (15)

10. What is the shape of the earth's orbit? How has this been deter- ined? Explain briefly one method. (15)

11. Explain fully why it is hotter in summer than in winter, and state he connexion between the sun's altitude at noon and its rising and setting laces. (15)

12. Explain the relationship between longitude and time. Describe ully one method of determining longitude. (15)

1899. MAY.

You are permitted to answer SIX *questions. Of these, two must be taken rom each series.*

SERIES I.

1. A piece of metal is placed in a balance and found to weigh 238 rains. When immersed in water the weight of the same piece of metal s reduced to 223 grains. State—
   (*a*) The cause of the difference of weight.
   (*b*) What the difference of weight represents.
   (*c*) The specific gravity of the metal.
   (*d*) The specific gravity of the water. (20)

2. A roll of copper-gauze, weighing fifty grains, is placed in a glass ube and heated while air is being drawn through it. Explain the follow- ng phenomena :—
   (*a*) The copper turns black.
   (*b*) On being weighed, its weight is found to be increased.

   And state—
   (*c*) Where the matter, which causes the increase of weight, comes from.
   (*d*) What is the nature and composition of the black material. (20)

3. Explain what is meant by the parallelogram of forces. (20)

4. Describe an experiment by which the laws of attraction and repulsion y magnets can be easily demonstrated. (20)

SERIES II.

5. (*a*) What is the object of having a bulb on a thermometer tube?
   (*b*) Why is mercury generally used as the fluid in a thermometer?

(*c*) State one cause which prevents the indications of the thermometer from being absolutely accurate. (15)

6. (*a*) State one method by which you can determine the specific gravity of sea-water.

(*b*) How can you obtain the materials held in suspension in sea-water?

(*c*) How can you obtain the materials held in solution in sea-water? (15)

7. Describe and state the mode of formation of the following—

(*a*) A medial moraine.

(*b*) A glacier-table.

(*c*) A glacier-mill (" moulin.") (15)

8. State the causes of the following phenomena exhibited in a volcanic eruption :—

(*a*) The red glow seen above the mountain.

(*b*) The dust which falls over the surrounding country.

(*c*) The streams of mud which flow down the mountain. (15)

Series III.

9. Explain fully the experimental proof of the rotation of the earth by means of the observation of the movement of Foucault's pendulum. (15)

10. Describe, with diagrams, the appearance of the moon in her orbit round the earth as seen from the earth. Why is it that we always see only the same side of her surface? (15)

11. What is meant by a parallel of latitude? Describe how the length in miles of a degree of latitude varies between the equator and the pole. Draw a diagram to illustrate this variation. (15)

12. Describe the behaviour of a magnetic needle mounted on a horizontal axis in the neighbourhood of London. State what would happen if it were carried—

(*a*) Towards the equator,

(*b*) Towards the north pole. (15)

1899. June.

You are permitted to answer SIX *questions. Of these, two must be taken from each series.*

Series I.

1. Draw a parallelogram to illustrate the action of two forces represented by the numbers 3 and 4 acting on a body in directions at right angles to one another, and show what the resultant force will be. (20)

2. I take a flask, put into it a piece of zinc, and pour over the zinc some dilute acid; I then close the mouth of the flask with a pierced cork in which a piece of glass tubing has been inserted. Explain what happens if I bring a lighted taper near the end of the glass tubing, and then hold a cold tumbler over it. (20)

3. What is meant by the "*specific gravity*" of a liquid? How would you determine the specific gravity of spirits of wine? (20)

4. Define the meaning of "*uniform linear motion.*"

tate whether the following examples represent such a motion, and if state why—

(*a*) A cannon ball shot vertically into the air.

(*b*) A ship sailing in still water in one direction under constant wind pressure.

(*c*) A train descending an incline without the use of the brake. (20)

SERIES II.

5. After a heavy fall of rain, 6 cubic inches of water were found in a rain-ıge. The area of the funnel of the gauge was 24 square inches. State at was the rainfall represented by the water collected. (15)

6. How does the water of a river differ from that collected in a rain-water tt? What is the cause of the difference? (15)

7. (*a*) What is pumice? (*b*) How does it differ from common volcanic riæ or cinders? (*c*) Why does pumice float in water? (15)

8. Draw sections showing the relations of a coral reef to the land in—

(*a*) A fringing reef,

(*b*) A barrier reef,

(*c*) An encircling reef. (15)

SERIES III.

9. What does Foucault's pendulum experiment teach us? Describe the in points of the apparatus he employed. (15)

10. What deductions can be made from observing throughout the year positions and lengths of the shadow (cast by the sun) of a vertical stick ced on a horizontal stand? (15)

11. Describe the method of determining the distance of the sun by ans of observations of Jupiter's satellites, and give numbers. (15)

12. Describe generally the magnetic state of the earth. How would ı prove that in Britain a magnetic needle mounted on a vertical pin does point to the true north? (15)

INDEX

The numbers refer to paragraphs, and not to pages.

THE END.

PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES.